GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. _____

Project No. E-25-674(R5286-0A1) GTRI/~~GIT~~ DATE 9 / 19 / 84

Project Director: Dr. William Z. Black MISC School/~~XXX~~ ME

Sponsor: Electric Power Research Institute

Type Agreement: Agreement No. RP254-6-1

Award Period: From 7/1/84 To ~~6/30/87~~ 9-30-87 (Performance) 6/30/87 (Reports)

Sponsor Amount:	This Change	Total to Date
Estimated:	$ 350,000	$ 100,000
Funded:	$ 350,000	$ 100,000

Cost Sharing Amount: $ n/a Cost Sharing No: n/a

Title: "Conductor Temperature Research"

ADMINISTRATIVE DATA OCA Contact Lynn Boyd X4820

1) Sponsor Technical Contact:

Mr. Vito J. Longo
Project Manager, Electrical Systems Dir.
EPRI
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

2) Sponsor Admin/Contractual Matters:

Ms. Virginia Hess or Ms. Tommi Smith
Contract Negotiator
EPRI
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303
(415)855 2207 (415)855-2226

Defense Priority Rating: n/a

Military Security Classification: n/a

(or) Company/Industrial Proprietary: n/a

RESTRICTIONS

See Attached n/a Supplemental Information Sheet for Additional Requirements.

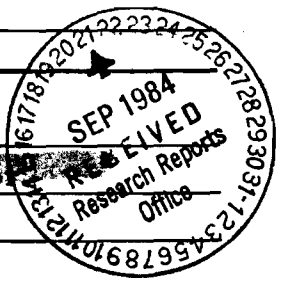
Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT; if unit cost is less than $25 000. Title vests with EPRI if the unit is greater than $25,000.00 (see Article 11)

COMMENTS:

(Budget forwarded to accounting ahead)

Deliverable Schedule will be forwarded at a later date due to need for clarification of report requirements.



COPIES TO:

Project Director
Research Administrative Network
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
Research Communications (2)
GTRI
Library
Project File
Other I. Newton

FORM OCA 4:383

Mat Hectmuller

EORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 9/15/87

oject No. E-25-674 School/~~Lab~~ XXX ME

cludes Subproject No.(s) N/A

oject Director(s) Dr. W. Z. Black GTRC XXXX

onsor Electric Power Research Institute

tle ~~EPRI~~ Conductor temperature research

fective Completion Date: 9/30/87 (Performance) 9/30/87 (Reports)

ant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [X] Final Report of Inventions – Sent questionaire to P.I.
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other _____

ntinues Project No. _____ Continued by Project No. _____

PIES TO:

oject Director
search Administrative Network
search Property Management
counting
curement/GTRI Supply Services
search Security Services
orts Coordinator (OCA)
al Services

Library
GTRC
Research Communications (2)
Project File
Other _____

RM OCA 69.285

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-01	4 (For EPRI Use Only)	School of Mechanical Engineering Georgia Institute of Technology Atlanta,GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
- Instructions for completing this form are on the reverse side.
- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual
													27
Actual (booked) cost in the current year 19 85	1	28	4	24	2	25	9	58	18	2	2	25	Current Year Actual: 198
Forecast to complete the current year 19 86	20	20	21	22	21	19	19	18	18	18	18	17	Current Year Forecast: 231

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
30					30

Grand total of lines (1) + (2) + (3) + (4) 486

Remarks: Comments on significant items

PREPARED BY

Print name Wm. Z. Black

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2514-01	4 (For EPRI Use Only)	School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
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- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	
													27	(1)
Actual (booked) cost in the current year 19 85	1	28	4	24	2	25	9	58	18	2	2	25	Current Year Actual: 198	(2)
Forecast to complete the current year 19 86	20	20	21	22	21	19	19	18	18	18	18	17	Current Year Forecast: 231	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
30					30 (4)

Grand total of lines (1) + (2) + (3) + (4) 486

Remarks: Comments on significant items

PREPARED BY

Print name Wm. Z. Black

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	For EPRI Use Only	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2, 546-01	4		Georgia Institute of Technology School of Mechanical Engineering Atlanta, Georgia 30332 (404) 894-3257
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87		

Note:
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- **Show EPRI portion of the contract only. Do not include contractor cost sharing.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual
													27 (1
Actual (booked) cost in the current year 19 85	1	28	4										Current Year Actual 33
Forecast to complete the current year 19 85				26	26	26	26	26	26	26	29	29	Current Year Forecast 240

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
					(4

Grand total of lines (1) + (2) + (3) + (4) 300

Remarks: Comments on significant items

PREPARED BY

Print name W. Z. Black

Professor

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	For EPRI Use Only	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 1494-02	4		School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From _____ to _____		

Note:
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- **Show EPRI portion of the contract only. Do not include contractor cost sharing.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec.	
Actual (booked) cost in the current year 19 85	1	28	4	24	2	25	9	58	18	2			171 (2)
Forecast to complete the current year 19 85											23	23	46 (3)

Prior Year(s) Actual	Current Year Actual	Current Year Forecast	Future Year(s) Forecast
27 (1)			

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	
					(4)

Grand total of lines (1) + (2) + (3) + (4) 244

Remarks: Comments on significant items

PREPARED BY

Print name Wm Z. Black

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 1775-61

EPRI CONTRACT NUMBER: RP 2515-4-6-0-1

EPRI PROJECT MANAGER: Name Vito Longo

EPRI CONTRACTOR NUMBER: 4 (For EPRI Use Only)

PERIOD OF PERFORMANCE: From 7/1/84 to 6/30/87

CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER:
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332

Note:
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	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual
Actual (booked) cost in the current year 19 86	30												225
Forecast to complete the current year 19 86	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual
		19	20	21	20	18	18	17	17	17	17	17	30
													Current Year Forecast
													201

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
30					30

Grand total of lines (1) + (2) + (3) + (4): 486

Remarks: Comments on significant items

PREPARED BY

Print name Wm. Z. Black

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER (For EPRI Use Only)	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-01	4	School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
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• Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual
Actual (booked) cost in the current year 19 86	30	9											225
Forecast to complete the current year 19 86			22	23	22	20	20	17	17	17	17	17	Current Year Actual 39 / Current Year Forecast 192

	19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
Forecast to complete the future year(s)	30					30

Grand total of lines (1) + (2) + (3) + (4) 486

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Remarks: Comments on significant items

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2154-6-[ ][ ]	[ ][ ] For EPRI Use Only	Wm. Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
• All figures are to be shown in U.S. dollars—whole thousands only.
• Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	Current Year Actual	Current Year Forecast	Future Year(s) Forecast	
Actual (booked) cost in the current year 19 86	30	9	13										225	52			(1) (2)
Forecast to complete the current year 19 86				24	23	21	21	18	18	18	18	18			179		(3)
Forecast to complete the future year(s)	19 87	19 ___	19 ___	19 ___	Remaining Years(s)											30	(4)
	30																
Grand total of lines (1) + (2) + (3) + (4)																486	

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Remarks: Comments on significant items

PREPARED BY

Print name Wm. Z. Black

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84A-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-01	For EPRI Use Only	Wm. Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
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• Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual
													225
Actual (booked) cost in the current year 19 86	30	9	13										Current Year Actual 52
Forecast to complete the current year 19 86				24	23	21	21	18	18	18	18	18	Current Year Forecast 179

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast
30					30

Grand total of lines (1) + (2) + (3) + (4) 486

Remarks: Comments on significant items

PREPARED BY

Print name Wm. Z. Black

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER (For EPRI Use Only)	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2 5 1 4 6 -		W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
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- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	
													225	(1)
Actual (booked) cost in the current year 19 ~~86~~	30	9	13	9	0								Current Year Actual: 61	(2)
Forecast to complete the current year 19 86						27	27	24	24	24	24	20	Current Year Forecast: 170	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
30					30	(4)

Grand total of lines (1) + (2) + (3) + (4) 486

Remarks: Comments on significant items

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EPRI

Item #31

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84A-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	For EPRI Use Only	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-1			William Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332 (404) 894-3257
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/20/87		

Note:
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- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	
													225	(1)
Actual (booked) cost in the current year 19 86	30	9	13	9	0	53	6	7					Current Year Actual: 127**	(2)
Forecast to complete the current year 19 86									23	23	22	21	Current Year Forecast: 89*	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
57					57	(4)

Grand total of lines (1) + (2) + (3) + (4)

Remarks: Comments on significant items

*Based on total authorized expenditures through Dec. 31, 1986 of $400,000 plus $41,000 proposed new funds for final quarter of 1986.

**Bills that have accured from Georgia Power sub-contract, but have not been paid by Georgia Tech through August 1986 total $33,118.

PREPARED BY

Print name

Title

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2516-[ ]	[ ] For EPRI Use Only	William Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332 (404) 894-3257
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/20/87	

Note:
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	Prior Year(s) Actual	
	225	(1)

Actual (booked) cost in the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
30	9	13	9	0	53	6	7					127**	(2)

Forecast to complete the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
								23	23	22	21	89*	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
57					57	(4)

Grand total of lines (1) + (2) + (3) + (4)

Remarks: Comments on significant items

*Based on total authorized expenditures through Dec. 31, 1986 of $400,000 plus $41,000 proposed new funds for final quarter of 1986.

**Bills that have accured from Georgia Power sub-contract, but have not been paid by Georgia Tech through August 1986 total $33,118.

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Title ___

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177-5 8/85

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-1	For EPRI Use Only	W. Z. Black (404) 894-3257 School Of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
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- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	
													225	(1)
Actual (booked) cost in the current year 19 86	30	9	13	9	0	53	6	7	13	39			Current Year Actual: 179	(2)
Forecast to complete the current year 19 86											19	18	Current Year Forecast: 37	(3)

Forecast to complete the future year(s)	19 87	19 __	19 __	19 __	Remaining Years(s)	Future Year(s) Forecast	
	57					57	(4)
Grand total of lines (1) + (2) + (3) + (4)						498	

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked

Remarks: Comments on significant items

PREPARED BY

Print name

Title

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	For EPRI Use Only	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2514 6-1			William Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332 (404) 894-3257
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87		

Note:
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- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	Current Year Actual	Current Year Forecast	Future Year(s) Forecast
Actual (booked) cost in the current year 19 86	30	9	13	9	0	53	6	7	13	39	9		225 (1)	188 (2)		
Forecast to complete the current year 19 86												28			28 (3)	
Forecast to complete the future year(s)	19 87	19 ___	19 ___	19 ___	Remaining Years(s)											
	57															57 (4)
Grand total of lines (1) + (2) + (3) + (4)																498

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked

Remarks Comments on significant items

PREPARED BY

Print name

Title ___

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84A

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	Wm. Z. Black, (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Long	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
• All figures are to be shown in U.S. dollars—whole thousands only.
• Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Prior Year(s) Actual	
	225	(1)

Actual (booked) cost in the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
30	9	13	9	0	53	6	7	13	39	9	9	197	(2)

Forecast to complete the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
13	13	13	13	12	12							76	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
						(4)

Grand total of lines (1) + (2) + (3) + (4) 498

Remarks: Comments on significant items

PREPARED BY

Print name

Title

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	William Z. Black School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/20/87	

Note:
- Instructions for completing this form are on the reverse side.
- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

		Prior Year(s) Actual	
		225	(1)

Actual (booked) cost in the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
30	9	13	9	0	53	6	7	13				140**	(2)

Forecast to complete the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
									25	25	26	76	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
57					57	(4)

Grand total of lines (1) + (2) + (3) + (4) 498

Remarks: Comments on significant items

**Bills that have accured from Georgia Power Subcontract but have not been paid by Georgia Tech through September 1986 total $39,736

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Print nar

Title

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
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- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Prior Year(s) Actual	
	422	(1)

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
0	15	15	15	15	16							76	(2)

Forecast to complete the current year 19 ___

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
													(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
						(4)

Grand total of lines (1) + (2) + (3) + (4) 498

Deliverable # 38

Remarks: Comments on significant items

PREPARED

Print na

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R-

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
• All figures are to be shown in U.S. dollars—whole thousands only.
• Show EPRI portion of the contract only. Do not include contractor cost sharing.

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual
0	17											17

Forecast to complete the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast
		12	12	12	12							48

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast

Prior Year(s) Actual	422
Current Year Actual	17
Current Year Forecast	48
Future Year(s) Forecast	
Grand total of lines (1) + (2) + (3) + (4)	487

Deliverable #39

Remarks: Comments on significant items

PREPARED

Print na

Title

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechaical Engineering Georgia Institute of Technology Atlanta, Georgia 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
- **Instructions for completing this form are on the reverse side.**
- **Figures *not* in U.S. dollars are to be shown in exact amounts, specifying type of currency.**
- **Figures in U.S. dollars are to be shown in whole thousands.**
- **Show EPRI portion of the contract only. Do not include contractor cost sharing.**

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prior Year(s) Actual	Current Year Actual
0	17	10										422	27

Forecast to complete the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast
			13	13	12							38

Unbooked liability

Please list dollar amount, (in whole thousands) description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Year(s)	Future Year(s) Forecast

Grand total of lines (1) + (2) + (3) + (4) 487

Remarks: Comments on significant items

PREPARED BY

Print name

Title

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
- Instructions for completing this form are on the reverse side.
- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual
0	17	10	19									46

Forecast to complete the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast
				9	9	8	8					34

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast

Prior Year(s) Actual	422
Grand total of lines (1) + (2) + (3) + (4)	502

Remarks: Comments on significant items

PREPARED BY

Print name

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2 5 4 1 6 - 1	For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/20/87	

Note:
- Instructions for completing this form are on the reverse side.
- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Prior Year(s) Actual	
	225	(1)

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
30	9	13	9	0	53							114	(2)

Forecast to complete the current year 19 86

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
						17	17	17	17	17	17	102*	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked

Forecast to complete the future year(s)

19 87	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
53					57	(4)
				Grand total of lines (1) + (2) + (3) + (4)	498	

Remarks: Comments on significant items *Based on total authorized expenditures through Dec. 31, 1986 of $400,000 plus $41,000 proposed new funds for final quarter of 1986. Bills that have accured, but have not been paid are as follows: Georgia Power (April 8181, May 7456, June 472, July 10,000, Aug. 7000) Total = $33,118.

Georgia Tech (expenses for summer quarter 1986) Total = $26,000.

PREPARED BY

Print name W. Z. Black

Title Professor

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note: • Instructions for completing this form are on the reverse side.
• All figures are to be shown in U.S. dollars—whole thousands only.
• Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Prior Year(s) Actual	
	422	(1)

Actual (booked) cost in the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
0	17	10	19	7	5							58	(2)

Forecast to complete the current year 19 87

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
					11	11						22	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
						(4)

Grand total of lines (1) + (2) + (3) + (4) 502

Remarks: Comments on significant items

*Deliverable #45

PREPARED BY

Print name

Title ___

EPRI

CONTRACTOR COST PERFORMANCE REPORT

EPRI 177 5/84R

EPRI CONTRACT NUMBER	EPRI DIVISION NUMBER	CONTRACTOR NAME, ADDRESS AND TELEPHONE NUMBER
RP 2546-[ ]	[ ] For EPRI Use Only	W. Z. Black (404) 894-3257 School of Mechanical Engineering Georgia Institute of Technology Atlanta, GA 30332
EPRI PROJECT MANAGER Name Vito Longo	PERIOD OF PERFORMANCE From 7/1/84 to 6/30/87	

Note:
- Instructions for completing this form are on the reverse side.
- All figures are to be shown in U.S. dollars—whole thousands only.
- Show EPRI portion of the contract only. Do not include contractor cost sharing.

	Prior Year(s) Actual	
	422	(1)

Actual (booked) cost in the current year 19 ___

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Actual	
0	17	10	19	7								53	(2)

Forecast to complete the current year 19 ___

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Current Year Forecast	
					9	9	9					27	(3)

Unbooked liability

Please list dollar amount, description of cost, and month/year in which costs are expected to be booked.

Forecast to complete the future year(s)

19 ___	19 ___	19 ___	19 ___	Remaining Years(s)	Future Year(s) Forecast	
						(4)

Grand total of lines (1) + (2) + (3) + (4) 502

Remarks: Comments on significant items

Deliverable #43

PREPARED BY

Print name

Title ___

Georgia Institute of Technology
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF MECHANICAL ENGINEERING
ATLANTA, GEORGIA 30332

October 2, 1984

Mr. Vito J. Longo
Project Manager, Electrical Systems
EPRI
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Dear Vito:

Here is my first "informal" monthly report on the conductor temperature project.

The Utility Survey Questionnaire has been completed and mailed to all those on the advisory committee. The final form of the questionnaire has incorporated input from the CIGRE survey as well as comments from the advisory committee.

The survey was taken to Illinois Power on August 20, 1984 and to Wisconsin Electric on August 21, 1984. Seven completed questionnaires have been received from these two utilities.

Two future trips are now in the planning stages: Tampa Electric on October 25th and a western trip to Idaho Power and PG and E on October 15-17th.

Two graduate programmers have been hired to revise and document the program. They have completely documented three of the 23 subprograms in the existing computer code. Work is underway to document two additional subprograms and it should be completed in the next two weeks. Documentation includes flow diagram, interpretive comment cards and list of symbols including units.

Preparation is underway for a brief presentation to the Conductor Temperature Working Group and to the Towers, Poles and Conductors subcommittee at the IEEE Winter Power Meeting in New York. The presentation will summarize the program objectives and progress made to date.

Sincerely,

Wm. Z. Black
Professor

WZB:maw

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E25-674

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

April 17, 1985

Mr. Vito J. Longo
Project Manager, Electrical Systems
EPRI
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Dear Vito:

Here is a brief summary of our progress during the period March 15 through April 15, 1985 on Project 2546.

1. Utility Survey

One additional utility survey has been received from Guive Nabet, Senior Engineer Electrical Engineering Dept., Baltimore Gas and Electric Co. His responses have been incorporated into the master questionnaire.

This brings the total number of engineers participating in the utility survey to 46 representing 21 utilities. No further responses are expected.

2. Development of DYNAMP

The verification and checking of DYNAMP has been completed. Flow diagrams and descriptions of all subroutines are practically finished.

3. Forest Park Test Span Facility.

The digital circuit that is used to access the weather data has been designed and built. Also the computer program that stores weather data and calculates average wind direction and provides that data in a more convenient format has been approximately one-half completed. The thermocouples for measuring the conductor temperature and the wires for control of the conductor current have been installed. The control

wires for measurement of the conductor sag have also been reinstalled.

No new line monitors have been received, although Niagara Mohawk has informed us that their model will be available for testing during the summer months.

4. Future Work

A program will be written which will permit direct input of weather data and line conditions collected on tape at the Forest Park Facility into the DYNAMP program. The program will serve as an interface between the Hewlett Packard Datalogger at Georgia Power and the CDC Cyber computer at Georgia Tech.

The present version of DYNAMP will be compiled on a IBM PC to determine if any modifications to the program must be made before the program can be executed on an IBM computer. Once an IBM compatible version of DYNAMP is available, a tape copy will be provided to EPRI.

DYNAMP will be used to generate typical ampacity curves expected for common conductor sizes when subjected to typical weather conditions. These curves will also be used as a check of all of the options within DYNAMP. Whenever possible the curves will be compared with existing and accepted ampacity data.

The guy wires and the load cell for the test span will be installed in the next two weeks. It is anticipated that the Linnet conductor will be re-energized and temperature data will be collected in the latter part of April.

Sincerely,

Wm. Z. Black
Professor

WZB:maw

E25-674

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

May 24, 1985

Mr. Vito J. Longo
Project Manager, Electrical Systems Div.
EPRI
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Dear Vito:

Here is a brief summary of our progress on the Conductor Temperature project for the period April 15 through May 15, 1985

1. Development of DYNAMP

DYNAMP is currently being modified so that it will compile on an IBM-PC. This task is far more involved than originally anticipated and it should be completed in 2 or 3 weeks if no further complications develop.

The scope of DYNAMP is being changed so that it can calculate conductor temperatures for a greater diversity of conductor types. The present version of the program will only consider three different conductor types while the new version will consider six different types of conductors. They are:

Case	Type	Conductor	Core
1	ACSR	1350-H19 Aluminum	Steel
2	AAC	1350-H19 Aluminum	1350-H19 Aluminum
3	AAAC	6201-T81 Aluminum	6201-T81 Aluminum
4	ACAR	1350-H19 Aluminum	6201-T81 Aluminum
5	All Copper	Hard Drawn Copper	Hard Drawn Copper
6	Alumoweld	1350-H19 Aluminum	Alumoweld

2. Forest Park Test Span Facility

Progress has been made in several areas relating to the Forest Park Test Facility. New thermocouples have been installed on the steel core and outer strands of the Linnet conductor and a new fiber optic link has been attached to the load cell. The Ontario Hydro sag

device has been pretested in the laboratory and the existing sag device installed on the conductor has been calibrated. The new guying design that will assure minimum pole deflection is now complete. Also new spacers that will be used to adapt the Linfo monitor to the larger conductor have been ordered.

3. Data Collection Project

A new program has been written so that data collected at the Forest Park Facility can be recorded on a floppy disc. The format of the data is such that the information can be interfaced directly with the IBM version of DYNAMP. Also the program that is used to poll the weather station and average the data for wind direction and speed has now been completed. Several other sites for collection of weather data in the Atlanta area have been investigated. The sites will be narrowed to one or two within the next month.

Sincerely,

Wm. Z. Black
Professor

WZB:maw

E-25-61

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Item #15

September 12, 1985

Mr. Vito J. Longo, Project Manager
Electrical Systems Division
EPRI
3412 Hillview Avenue
Palo Alto, CA 94303

Dear Vito:

Here's a brief report of our progress since our Atlanta meeting on July 30th.

1. Development of DYNAMP

Version 1.1 of DYNAMP is nearing completion and it will be offered within the next few weeks to those who have version 1.0. The new version of DYNAMP contains several improved features not available in the original version. Three errors were corrected in the WIRE DAT file and one error has been corrected in the file called WIRED. Also the program has been modified and expanded to accommodate an additional conductor type. Furthermore, DYNAMP has been modified so that it can calculate ampacity values for an unlimited number of ambient conditions rather than data arrays that are limited to less than 200 values.

2. Program Verification

DYNAMP has been used to analyze approximately one week of ampacity values for the Curlew conductor. The program accuracy is similar to that experienced with the Linnet conductor, although the program consistently overestimates the conductor temperature by approximately 10°C. Additional measured temperatures have been collected on disc for the Curlew conductor, but the data has not been analyzed with DYNAMP.

3. Temperature Gradients in Conductors

A detailed analytical study of the temperature gradients that occur within conductors has been completed. Mr. Stuart Collins recently completed his master's degree requirements and a copy of his thesis is enclosed. The analysis allows calculation of the temperature gradients in ACSR, AAC and all copper conductors operating under all types of weather conditions. The results show that ampacity calculations can be accurately made without considering the temperature differences in the conductor, even though in extreme conditions the temperature differences that may exist in ACSR conductors can be as high as 10-15°C.

4. Planning for Seminars

Planning for the two Spring seminars is proceeding satisfactorily. Announcements will be mailed within the next two weeks. Both seminars will be held in Atlanta at the downtown Days Inn. The seminar on the Effects of Elevated Temperature Operation on Overhead Conductors will be held on May 20, 1986, and the seminar on Real-Time Ampacity Ratings of Overhead Conductors will take place on May 21, 1986. The seminars are being coordinated with the Aluminum Association and both the South Eastern Electric Exchange and IEEE have been contacted for appropriate mailing lists of possible participants.

5. Operation of Test Facility

Several additional weeks of temperature data has been collected for the Curlew conductor. The data acquisition program has been modified so that data on time intervals of two minutes can be obtained. These data will be used to determine the effect of data frequency on the accuracy of real-time ampacity calculations.

6. Line Monitor Equipment

The Linfo device has had a failure in the receiving equipment and at the present time it is being repaired.

The Creative Power System's Real-Time Temperature Device will be delivered next week and it will be checked out and installed on the test line when it is received.

Sincerely yours,

William Z. Black
Professor

WZB:pat

Attachment

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

November 5, 1986

Mr. Vito J. Longo
Project Manager, Electrical Systems
EPRI
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Dear Vito:

Here's a brief report on our progress on Project 2546 since the Paris CIGRE meeting.

1. Development of DYNAMP

Version 1.2 of DYNAMP has been completed and the user's manual has been changed to reflect operation of the revised program. Version 1.2 differs from 1.1 in the revisions that were outlined in the last quarterly report presented in Boise Idaho.

Two copies of Version 1.2 have been mailed in addition to the copy that I mailed to you in October. They were sent to R. A. Fiqueroa of San Diego Gas and Electric and J. J. Hipius of Niagara Mohawk Power Corporation.

2. Program Verification

All line temperature data collected at the Forest Park test site has been analyzed with DYNAMP and the difference between the measured temperatures and predicted values have been analyzed with our statistical package. Errors continue to be less than 10°C for more than 92% of the data points and over 75% of the data is within 5°C of the temperatures predicted by DYNAMP.

Weather data at the four sites remote from the Georgia Power test span has been collected and put into DYNAMP. These data were obtained over a common three week period at sites between two miles and 30 miles from Forest Park. All of these data have been collected as part of the Idaho Power project and they have been run through DYNAMP, but not yet analyzed statistically. However preliminary

analysis shows the obvious result that DYNAMP's accuracy falls off dramatically as the weather station moves further from the test span. Errors in the DYNAMP temperature ranged up to 65°C from the farthest weather station.

Several problems have surfaced with the remote station weather data. For two of the weather stations, the data are recorded on strip charts and the data must be taken from the chart by hand before they can be placed on diskette. This process is time consuming and very subject to error. Small errors in recording either the wind velocity and, to a lesser degree, the wind direction are known to produce large errors in the predicted temperature. Furthermore one of the weather stations contained data collected on 15 minute intervals. These data are far enough apart that they are practically the same as the thermal time constant of the line. Therefore DYNAMP sees nearly steady state data when it processes weather data on such a long time interval. A clearer picture of how these factors affect the program accuracy will appear after all of the data are analyzed with the statistical package.

The Forest Park test span has been partially dismantled and it is no longer operational.

KEURP Project

The data collection phase of the KEURP project has now been completed, but the data has not yet been sent to Georgia Tech. Conditions have been recorded for a minimum of three days for four different line sizes. Gary Thomann has used some the data in DYNAMP and he has compared DYNAMP's predictions with the CPS line monitor measurements. DYNAMP worked satisfactorily through all these checks according to Gary Thomann.

The line monitor has been returned from Kansas and it has been placed on the Georgia Power test span for recalibration. The line monitor was operated for three weeks during October before the line was disassembled.

Preparation for 1986 Summer Meeting

Jeff Jerrell, Tom Parker and I are in the initial phases of putting together a paper for the Summer Meeting. It will deal with the subject of critical spans and it will base its conclusions on the remote site weather data and how DYNAMP's accuracy varies with distance between the span

and the weather station. Jeff has also finished his analysis of the sensitivity parameters and he has then plotted for typical operating parameters. We plan to use the sensitivity parameters to back up our conclusions about critical spans.

Sincerely,

William Z. Black
Professor

WZB:maw

cc: Stan Harper
Rick Bush

June 24, 1985

Mr. Vito J. Longo
Project Manager, Electrical Systems
EPRI
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Dear Vito:

Here is a brief summary of our progress during the period May 15 through June 15, 1985.

1. Utility Survey.
Two additional utility surveys were received during this month. They are from:

Don Smith
Transmission Planning Manager
Georgia Power Company

J. A. Babbitt
Supervisor of System Planning
Gulf Power Company

Responses for these two surveys are being incorporated into the master questionnaire.

2. Development of DYNAMP
The IBM-PC version of DYNAMP has been completed and a preliminary floppy disk copy was forwarded to EPRI. In addition a rough cut version of a users manual to accompany the program has been sent to EPRI.

Additional statements have been included in the program to warn the user to improper operation. Modifications have been made to the program so that it is capable of predicting conductor temperatures for six different conductor types have been completed.

3. Data Collection Project
A computer program that modifies the Georgia Power test data and puts it into a form that can be directly interfaced with the IBM-PC version of DYNAMP has been completed.

4. Forest Park Test Span Facility

The Ontario Hydro sag monitor has been installed and tested. The output of the device has been interpreted and its accuracy has been evaluated. This device will be returned to Ontario Hydro.

All thermocouples have been removed from the Linnet conductor in preparation for installation on the 1033 conductor. One of the two poles that will be used in conjunction with the measurement of support deflection has been installed and the modifications necessary for the relaying of the new conductor have been started.

5. Planning for Symposium

The Aluminum Association has been contacted and notified of our intent to offer a symposium on the operation of overhead conductors at elevated temperatures. The Electrical Division of the Aluminum Association has agreed to co-sponsor this event.

6. Planning for Quarterly Meeting

The next quarterly progress meeting will be held at Georgia Power Research and Test Laboratory in Forest Park, Georgia on Tuesday July 30, 1985. An attached agenda of the meeting will be mailed to each member of the Task Force.

Respectfully submitted,

Wm. Z. Black
Professor

WZB:maw

Enclosure

June 24, 1985

M E M O R A N D U M

TO: EPRI Task Force for Conductor Temperature Project

FROM: Wm. Z. Black, Project Director

SUBJECT: Task Force Meeting on July 30, 1985

This memo is a reminder that the EPRI Task Force for the Conductor Temperature Research Project (Project 2546) will meet on Tuesday July 30, 1985 at 9:00 am at Georgia Power's Research Center in Forest Park, Georgia. A map indicating the route from the Atlanta Airport to the Research Center is enclosed. Call me at (404) 894-3257 if you need additional information concerning our meeting.

The agenda for the meeting is as follows:

A. Discussion of Progress
   1. Development of Ampacity Program (DYNAMP)
   2. Accuracy of Program - Comparison with Test Line Data
   3. Preliminary Feedback from Utilities on Program Usage
   4. Results of Test Facility Modifications
   5. Results of Line Monitor Evaluations
   6. Evaluation of Collected Test Data
   7. Discussion of Critical Span Analysis

B. Future Work
   1. Further Developments for DYNAMP
   2. Further Work on Test Facility
   3. Proposed Work for Critical Span Analysis
   4. Planning for 1986 Symposium on Effects of Elevated Temperatures Operation on Overhead Conductors

Revisions to the DYNAMP program have delayed its availability. However, preliminary copies of DYNAMP along with a user's manual will be available at the meeting.

maw

Georgia Institute of Technology
School of Mechanical Engineering Atlanta, Georgia 30332

An Equal Education and Employment Opportunity Institution

A Unit of the University System of Georgia

EPRI RP 2546
CONDUCTOR TEMPERATURE RESEARCH

TASK FORCE MEMBERS

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GEORGIA TECH

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Progress Report

EPRI Project 2546

CONDUCTOR TEMPERATURE RESEARCH

Georgia Intitute of Technology
School of Mechanical Engineering

and

Georgia Power Company
Research and Test Laboratory

July 1 - November 30, 1984

I. GENERAL

The contract between Georgia Tech and EPRI was formally started on July 1, 1984. The subcontract with Georgia Power Company was delayed and was eventually signed on October 22. As a result this report summarizes a 5 month effort for Georgia Tech and a one month effort for Georgia Power.

Three undergraduate students were hired on an hourly basis at Georgia Tech and their responsibilities were to check and optimize operation of the ampacity program. An additional graduate student has been hired on a Research Assistantship to investigate the problem of internal temperature gradients inside the conductor. This project will form the basis for the students Master's thesis requirement and his work will be completed in approximately six quarters.

II. ORGANIZATIONAL MEETINGS

A kickoff meeting was held in Atlanta at the Georgia Power Research and Test Laboratory in Forest Park on August 7, 1984. During that meeting the capabilities and limitations of the program were outlined. Numerous suggestions were made to modify the program so that it would be of greatest use to the utility industry. The program is written in FORTRAN 77 language and it eventually will be incorporated into the EPRI Workstation Software as well as into the various utility mainframe computers.

During the kickoff meeting the utility survey was discussed and numerous modifications were suggested. The suggestion was also made to incorporate parts of a similar CIGRE survey into the questionnaire. Initial plans were made to visit several utilities to discuss the objectives and goals of the conductor temperature research project and to complete the survey. It was also recommended to review rating standards from as many companies as possible. The rating standards are to be collected during the visits to each utility.

The section in the proposal entitled Alternate Site Recommendations was discussed. At the present time work outlined in this section will be eliminated and all experimental work will be carried out at the Georgia Power Company Research Laboratory. The work originally scheduled within this section will be replaced by an effort to assemble and evaluate all available conductor temperature monitoring equipment. Equipment will be purchased and installed on the test span at Forest Park. The equipment accuracy, capabilities and limitations will be compared.

A quarterly organizational meeting has been scheduled to coincide with the New York IEEE Winter Power Meeting on February 3, 1985. At that time a presentation on initial achievements will be made to the Overhead Ampacity Working Group and the Towers, Poles and Conductors Subcommittee.

The kickoff meeting concluded with a tour of the Georgia Power Research and Test Laboratory which includes the instrumented overhead conductor test facility.

III. UTILITY SURVEY (Task I)

A survey was formulated for the purpose of providing utility input in the early developmental stages of the computer program. The responses to the questions in the survey were used to provide direction so that the computer program will eventually receive the greatest possible use throughout the industry.

The questions used in the survey came from a combination of sources. Some questions were taken from a survey conducted by CIGRE. Others were inserted into the survey for the purpose of determining how the industry will ultimately want the computer program designed.

The survey is subdivided into four sections.

Section I Operation of Transmission and Distribution System

Section II Steady State Ampacity Calculations

Section III Real-Time Ampacity Calculations

Section IV Ampacity Instrumentation and Critical Span Analysis

A copy of the questionnaire is provided in the appendix to this report.

The survey was mailed to the utilities that have an interest in a project of thermally rating overhead lines. In addition five companies were visited to conduct discussions on the project and to collect the completed surveys. All discussion periods were recorded on tape. Rating manuals have been collected for most of the companies. At this time the following utilities have been visited:

Illinois Power Company on August 20

Wisconsin Electric Company on August 21

Pacific Gas and Electric Company on October 15

Idaho Power Company on October 17

Tampa Electric Company on October 25

An additional discussion period is being planned to coincide with the IEEE Winter Power Meeting in New York. It is hoped that representatives of Ontario Hydro, Rochester Gas and Electric, Niagaria Mohawk and Boston Edison will attend this meeting and also complete the questionnaire.

Thus far 41 people representing 16 different companies have either participated in the group discussions and or have completed the questionnaire. (See Table below) The survey has also been mailed to interested parties at TVA, Georgia Power, Mississippi Power, Gulf Power and Alabama Power. Responses from these companies will be compiled when the surveys are returned.

The questions in the utility survey concerning present practice used by the various utilities revealed several unanimous points. None of the utilities respnding to the survey presently have the capability to measure the temperatures of their overhead transmission conductors; and yet every company expressed a desire to utilize a real-time ampacity program to predict actual conductor temperatures when such a program becomes available. Another question receiving a unanimous vote was the one which asked which system of units was preferred when using an ampacity program. All companies expressed a desire to use the English system of units except the unit for temperature. Most preferred to use the Fahrenheit degree when measuring the air temperature and the Celsius degree when specifying the conductor temperature. One final area that received a unanimous vote concerned the way in which the responding utilities presently rate overhead conductors. All companies rate their systems on the basis of a single winter and a single summer air temperature and all companies consider that the air flow across the conductor takes place perpendicular to the conductor. With the exception of one company, all those who responded to the survey indicated that they do not consider separate

COMPANY	NAME	TITLE
City of Lakeland-Electrical Utilities	J. H. Curran	Supervisor, Substation Engineering
	L. Duffey	Electrical Engineer
Florida Power & Light Co.	J. G. Raine	Staff Engineer, Systems Operations
	J. Renowden	Principal Engineer, Substation/ Transmission Design
	J. Rhine	Principal Engineer, Substation/ Transmission Design
	W. R. Sooty	Senior Engineer General Engineering
Florida Power Corp.	H. E. Brown	Senior Engineer, Transmission Standards
Gainesville Regional Utilities	R. C. Watkins	Senior Engineering Assistant
Idaho Power Company	M. D. Hanson	Engineer, Transmission Dept.
	M. R. Noland	Supervisor, Power Operations
	R. W. Wall	Electronics Design Engineer
Illinois Power Co.	W. L. Calhoun	Supervisor, Transmission Design
	R. L. McPherron	Supervisor, Transmission Planning
	J. D. Spencer	Director, Transmission and Distribution Design
	R. L. Trotter	Manager of Engineering
Jacksonville Electrical Authority	J. A. Dickinson	Transmission Supervisor
Madison Gas and Electric Co.	L. E. Schuab	Transmission Engineer
Niagara Mohawk Power Corp.	J. J. Hipius	Lead Transmission Planning Engineer
Orlando Utilities Commission	R. Zell	Assistant Director, Systems Planning Division

PARTICIPANTS IN UTILITY SURVEY

COMPANY	NAME	TITLE
PG and E	A. C. Agboativala	Senior Energy Service Engineer, Dept. of Engineering Research
	R. S. Baishiki	Senior Electric Engineer
	R. Bunten	Senior Operations Engineer
	J.Hall	Engineering, Dept. of Engineering Research
	P. Lai	Engineer, Transmission Planning
	H. Lee	Engineer, Overhead Transmission
	J. T. Morgan	Supervising Electrical Engineer, EE Dept.
	N. Solloway	Engineer, Transmission and Distribution
Seminole Electric Co-op	W. Altman	Transmission Engineer
Southwestern Electric Power Co.	W. A. Lacefield	
Tampa Electric Co.	R. Donahey	Assistant manager, Systems Operations
	T. Ithier	Principal Engineer, Control Systems
	T. L. Porter	Manager, Transmission Engineering
	G. Ramon	Manager, Transmission Planning
	J. Wilsky	Senior Engineer Control Systems
Wisconsin Electric Power Co.	J. A. Becker	Transmission Planning
	P. E. Hesse	Transmission Planning
	J. P. Nesbitt	Operations Engineer, Systems Operations
	R. C. Nichols	Senior Project Engineer, Transmission Design
	J. W. Schriener	Systems Operator
	T. W. Wick	Project Engineer Systems Operation
Wisconsin Public Service Corp.	R. J. Ellifson	Associate Engineer, Sustation and Transmission Dept.

PARTICIPANTS IN UTILITY SURVEY

daytime and nightime ratings. None of the companies calculate a fault conditions ampacity value. And finally, none of the utilities consider magnetic heating, evaporative cooling or a temperature gradient within the conductor when they calculate ampacity values.

Questions other than those mentioned in the previous paragraph received less than unanimous votes and as a result these results became somewhat more difficult to interpret. For example, several of the questions were formulated to determine whether most of the utilities would have the facilities to monitor weather conditions within their service area, because a real-time ampacity program would require up-to-date weather data as input. Seventy-five percent of the companies that responded to these questions stated that they had the capability to monitor weather conditions within their service area at least at one location. It is probably safe to say that no company would presently have a sufficient number of weather stations to provide adequate input to a real-time ampacity program. In other words, if a company wished to achieve a reasonable accuracy from a real-time ampacity model over their entire service area, they would certainly have to install a greater number of weather stations.

Seventy-five percent of the utilities stated that they had the ability to calculate their own steady state ampacity value. The various forms of the steady-state ampacity values that are presently used by the various utilities are quite different. Ampacity values are primarily in the form of tables and they appear to be fairly evenly split between the aluminum association tables, manufacturer tables and tables that were developed with internally generated computer programs. The most frequently mentioned program was one based on the House and Tuttle method. The conditions used in the ampacity tables are fairly consistent among those utilities that have steady-state ampacity

programs. Two-thirds of those who responded report that they calculate their ampacity values for a constant wind velocity of 2 ft/sec. The remainder use a velocity of 4.4 ft/sec with the exception of one company which calculates ampacity based on a zero wind velocity. Two-thirds of the companies account for solar heating of the conductor while the remainder ignore the influence of the sun when determining the temperature of the conductor. With the exception of one company, the emissivity and absorptivity of the conductor, regardless of whether the conductor is aluminum or copper, is assumed to be 0.5. None of the companies consider the effect of age on the radiation properties of the conductor.

All companies calculate a normal ampacity rating, while only seventy-five percent calculate an emergency ampacity rating. Normal ampacity values correspond to a wide range of conductor temperatures, the most common value being 75°C. The maximum temperature used for a normal rating is 120°C while some companies provide for different ratings depending upon the construction of the conductor. Of those companies that consider emergency ratings, the most commonly mentioned limiting time for an emergency rating was two hours. Other values for a limiting time during which an emergency overload would be tolerated ranged between 30 minutes and 4 hours and one company permitted emergency conditions to exist for up to 500 hours per year. The temperatures that were acceptable during the emergency current overload ranged between 80°C and 140°C with the most commonly mentioned figure being 93°C. Some companies have established different acceptable values for emergency ampacity calculations depending upon different types of conductor construction. They have established relatively low values for emergency temperatures for hard drawn copper conductors and progressively higher acceptable values for AAC and ACSR conductors.

The reasons that the various utilities give for selecting the maximum limiting conductor temperature is evenly split among the following factors: clearance, loss of strength, creep, degradation of splices and economic factors. The two considerations that did receive a slightly greater consideration were clearance and loss of strength. Several of the utilities that were interviewed made the statement that limiting ampacity values should ultimately be set on the basis of clearance and other factors should play only a very minor role in dictating operating temperatures of the conductor. Several utilities had experienced splice failures throughout their overhead network and they were being forced to face the problem of replacing or upgrading numerous splices. These particular utilities obviously placed a greater emphasis on selecting a limiting temperature that would protect the integrity of their splices and they placed very little importance on the clearance as a factor which should dictate maximum operating temperatures.

While practically all of those companies that were surveyed had the ability to calculate steady-state ampacity values, very few of the utilities have the capability to predict real-time ampacity values. Only one-fourth of the utilities at the present time are capable of calculating real-time ampacity values. All companies would use a real-time ampacity program if it were available and they would expect that program to predict the conductor temperature to within $\pm$ 5^{o}C of the actual temperature. Two companies placed a high priority on developing a real-time ampacity program, seven felt that they had a moderate priority for such a program and four placed a low priority on such a program. The highest priority for the development of a real-time ampacity program came from the operating engineers followed by planning engineers and the design engineers felt they would be the ones who would be least likely to use the program. When asked what type of computing equipment

would be most likely used to run the program, the response showed an even split between a mainframe computer and a personal computer.

The form of the output information provided by the computer program seems to depend greatly upon who will be using the program. The operating engineers made a very strong case for a program output that is very simple and easy to interpret. They are not particularly concerned about a program that is very general or one which will apply to the broadest range of conductor geometries and weather conditions. When asked how the program should convey real-time information to the user, the operating engineer showed a strong preference for the output of a single value that would predict the time a conductor would reach a predetermined limiting temperature. The designers and planners, on the other hand, were not concerned about the simplicity of the output, but they expressed a desire that the program be general enough to handle all types of conductors and all possible weather conditions that could possibly exist within their service area.

Even though none of the utilities surveyed are presently measuring the temperature of any of their conductors and even though only two out of eleven companies that were surveyed said they had any future plans to install temperature measuring devices on their energized lines, seventy percent of the utilities said that they would purchase line monitoring equipment if it were reliable and readily available at a cost between $10,000 to $15,000. The number of devices that these utilities would purchase ranged between two and ten. The most commonly used reason for purchasing this type of equipment was to have a means of checking the accuracy of a real-time ampacity computer model. Most people felt that when the instruments had proven the accuracy of the model, they would not continue to use the devices their system. When asked whether an on-line instrument or a computer model would provide the

greatest confidence in knowing the temperature of an overhead conductor, the response was equally split. It appears that design engineers place more confidence in a computer model while planners and operating engineers seem to feel more confident with an on-line monitor.

The questions regarding the concept of critical span and how the industry views this concept seem to indicate that most utilities either do not subscribe to the concept of a critical span, or if they do, they are not sure how to utilize the concept when rating their transmission network. Only thirty percent of the comapnies utilize the concept of a critical span in determining the real-time rating of their network. Of these companies some had difficulty defining what actually constitutes a critical span, but the most frequently given definition of a critical span was simply the span which had the highest temperature. Most of those who subscribed to the concept of a critical span simply said that a critical span was one that had experienced thermal problems in the past and a few people said that a critical span could be identified by locating those spans that had experienced exceptional load growth in the past.

FUNCTION DENSTY

Purpose: This function subprogram calculates the density of atmospheric air at the ambient air temperature and local atmospheric pressure.

Input: Z: elevation in meters
TEMP: local atmospheric temperature in ^{o}C

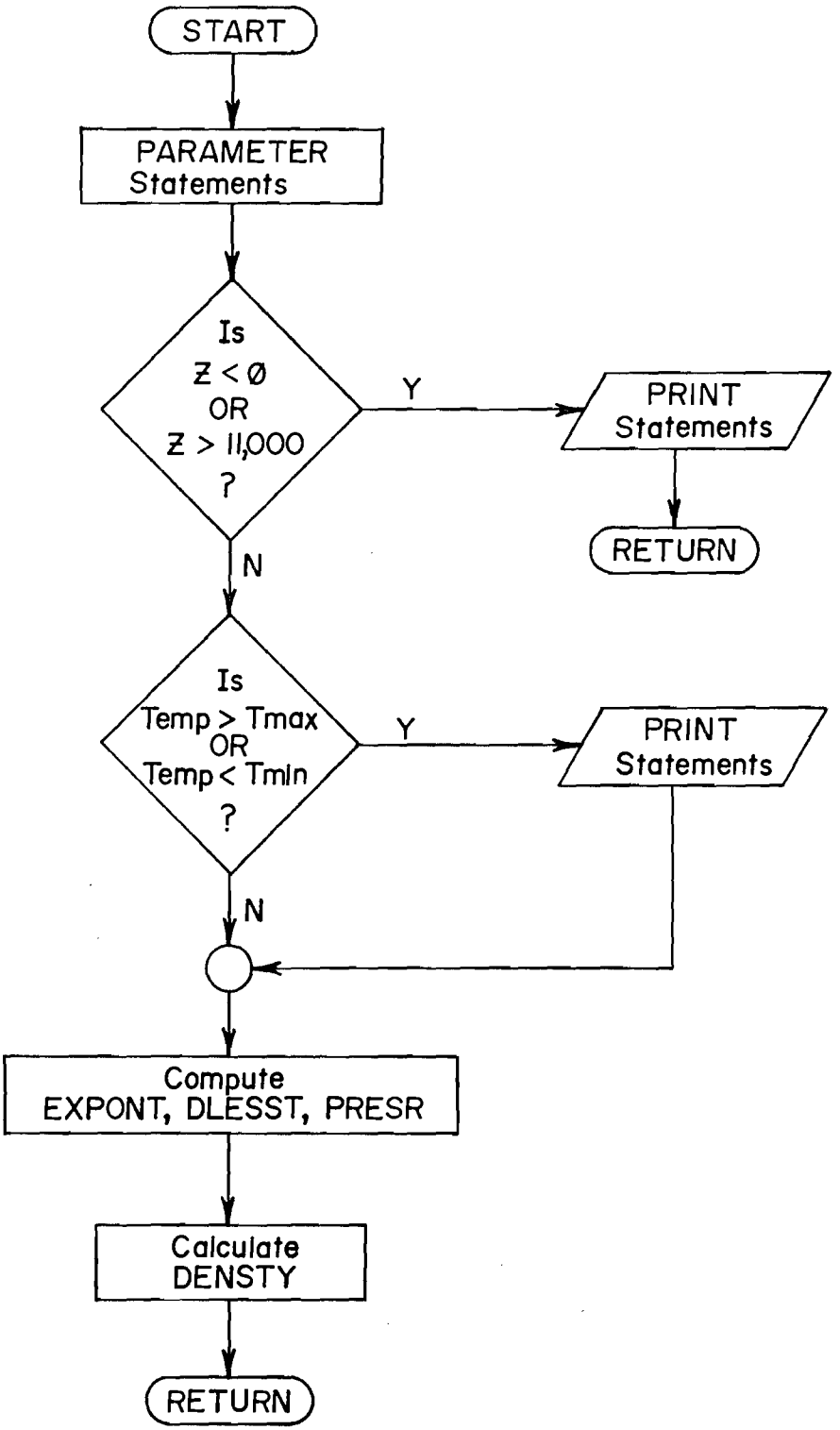
Output: DENSTY: density of air in kg/m^3

Common Blocks:

Computer Symbols and Description of Variables:

Symbol	Description	Units
ALPHA	Lapse rate of the atmosphere	$^{o}C/m$
DENSTY	Density of air	kg/m^3
DLESST	Dimensionless constant	
EXPONT	The value of the exponent in calculations	
G	Acceleration to gravity	m/s^2
PRESSL	Pressure at sea level	KPa
R	Ideal gas constant	
TEMPSL	Temperature at sea level	^{o}C
TMAX	Maximum temperature for which calculations are valid	^{o}C
TMIN	Minimum temperature for which calculations are valid	^{o}C

FUNCTION DENSTY



```
      FUNCTION DENSTY (Z, TEMP)
*************************************************************************
*   THIS FUNCTION COMPUTES THE DENSITY OF ATMOSPHERIC  AIR  IN KG       *
*  PER CUBIC METER AS A FUNCTION OF THE ELEVATION (Z) IN METERS,        *
*  AND THE AMBIENT TEMPERATURE (TEMP) IN DEG C .                        *
*************************************************************************

      PARAMETER (G = 9.807, TEMPSL = 15.0, PRESSL = 101.3 ,R = 0.287)
      PARAMETER (ALPHA = 0.0065, TMAX = 400.0, TMIN = -40.0)
      PARAMETER (ZMIN = 0.0, ZMAX = 11000.0)

      IF ((Z .LT. ZMIN) .OR. (Z .GT. ZMAX)) THEN
         PRINT*, ' UNREALISTIC INPUT DATA FOR ELEVATION '
         PRINT*, ' PLEASE CHECK YOUR INPUT DATA. PROGRAM IS TERMINATED'

      RETURN
      END IF

      IF ((TEMP .GT. TMAX) .OR. (TEMP .LT. TMIN)) THEN
         PRINT 44,' TEMP IS OUT OF RANGE OF RESISTIVITY EQUATIONS'
         PRINT 22, ' SINCE TEMPERATURE IS ', TEMP, ' DEG C'
22       FORMAT (2X, A, F5.1, A)
         PRINT 44, ' HOWEVER, CALCULATIONS WILL CONTINUE'
44       FORMAT (2X, A)
      END IF

*************************************************************************
*  CALCULATION OF ATMOSPHERIC PRESSURE VARIATION WITH ELEVATION         *
*************************************************************************
      EXPONT = G / (R  * ALPHA * 1000.0)
      DLESST = ((TEMPSL + 273.15) - ALPHA * Z) / (TEMPSL+ 273.15)
      PRESR = PRESSL * ((DLESST)**EXPONT)

*************************************************************************
*  CALCULATION OF ATMOSPERIC DENSITY USING IDEAL EQUATION OF STATE      *
*************************************************************************
      DENSTY = PRESR / (R * (TEMP + 273.15))

      END
```

FUNCTION HTC

Purpose: This function subprogram calculates the free and forced convection heat transfer coefficient for the conductor in the surrounding air. The forced convective heat transfer coefficient is primarily a function of the air velocity. The free convection heat transfer coefficient is primarily a function of the temperature of the conductor above the ambient air temperature.

Input: TIME: The local time which in turn can be used to calculate the values for the local weather conditions such as wind velocity and air temperature.

TEMP: The conductor temperature in degrees C.

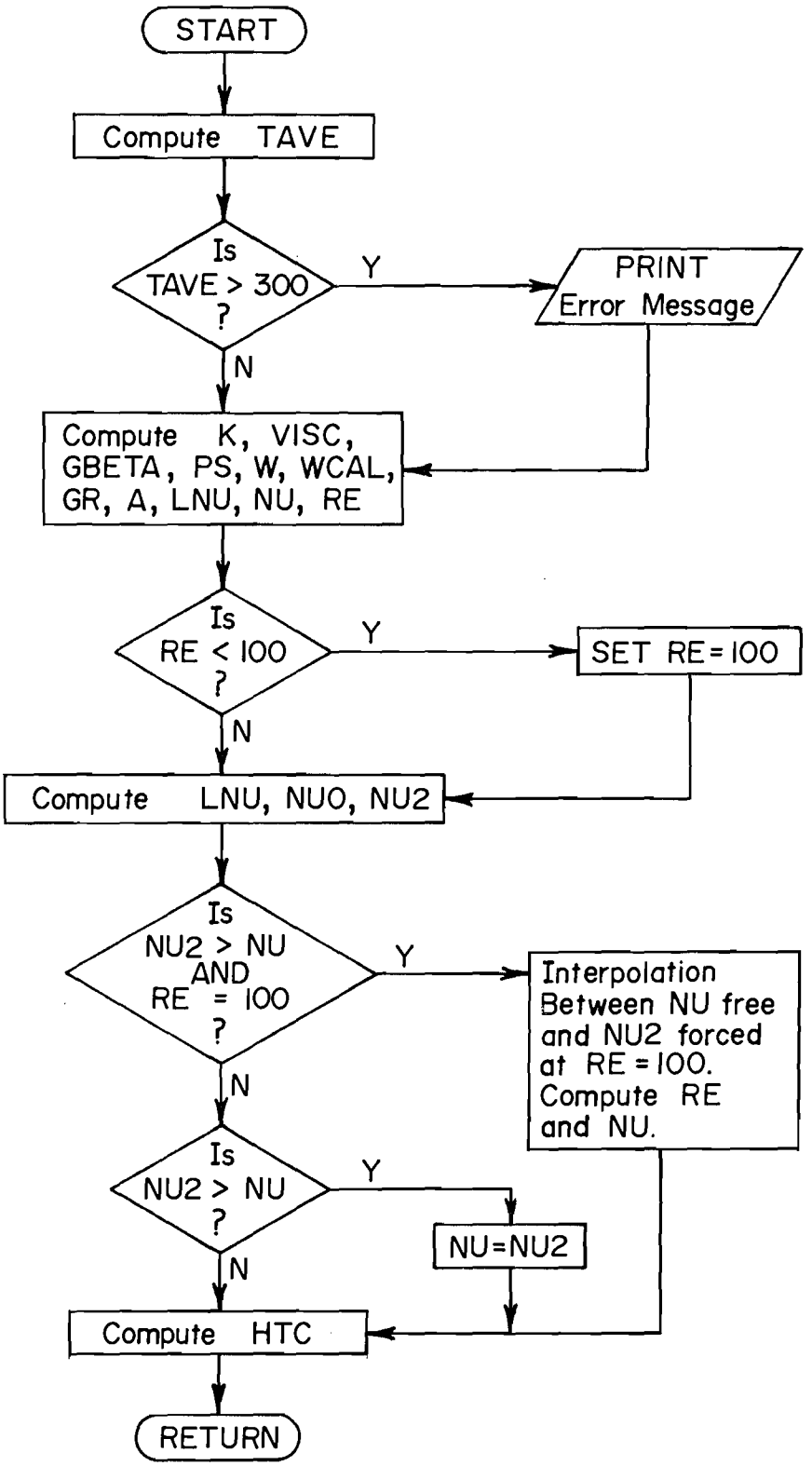
Output: HTC: The convective heat transfer coefficient from the conductor to the surrounding air in $W/m^2\ ^oC$.

Common Blocks:

Computer Symbols and Description of Variables:

Symbol	Description	Units
A	Nusselt parameter for free convection	
A0,A1,A2,A3	Coefficients for free convection	
B1,B2,B3	Coefficients for forced convection	
DENS	Density of air at average air temperature and local elevation	kg/m^3
GBETA	$g\beta/\nu^2$ for air	$1/m^3\ K$
GM	Line axis orientation from south radial	
GR	Grashof number of air	
K	Thermal conductivity of air	$W/m\ ^oC$
LNU	Logarithm to the base of 10 for the free convection Nusselt number	
NU	Nusselt number	
NUO	Forced convection Nusselt number uncorrected for wind incidence angle	
NU2	Forced convection Nusselt number	
PR	Prandtl number for air	
PS	Wind direction from south	radians
PSI	Wind direction from south	degrees
RE	Reynolds number of air	
S	Slope of interpolation calculations	
TAIR	Ambient air temperature	^oC
TAVE	Average of TAIR and TEMP	^oC
VAIR	Wind velocity	m/s
VISC	Dynamic air viscosity	Ws^2/m^3
W	Correction parameter for wind incidence angle	
WCAL	Correction parameter for forced convection	
Z	elevation	m

FUNCTION HTC



```
      FUNCTION HTC(TIME,TEMP)
C*************************************************************
C*    THIS FUNCTION SUBPROGRAM CALCULATES THE FREE AND FORCED *
C*   CONVECTION HEAT TRANSFER COEFFICIENT FOR A CYLINDER IN   *
C*   WATTS PER METER SQUARED DEGREES C AS A FUNCTION OF       *
C*   CONDUCTOR TEMPERATURE IN DEGREES C.                      *
C*************************************************************
      REAL K,NU,LNU,NUO,NU2
      COMMON/BDIA/DIA,Z/BLG/BETA,GAMMA
C
      DATA A0,A1,A2,A3/.12724,.02238,.042030,-.0025973/
      DATA B0,B1,B2,PI/-.070431,.31526,.035527,3.14159/
C
      TAIR  =  TINF(TIME)
      TAVE  =  (TEMP+TAIR)/2.
C
      IF (TAVE.GT.300.) THEN
         PRINT*,'TEMP IS OUT OF RANGE OF PROPERTY EQUATIONS'
      ENDIF
C
C*************************************************************
C*    CALCULATION OF PROPERTIES AS A FUNCTION OF THE AVERAGE
C*    TEMPERATURE AND THE ELEVATION.
C*************************************************************
      PR  =  0.71
      K  =  -2.7628E-08*(TAVE**2.) + 7.2316E-05*TAVE + 2.3681E-02
      VISC  =  3.954E-08*TAVE + 17.456E-06
      DENS  =  DENSTY(Z,TAVE)
      GBETA  =  9.807 / ((TAVE + 273.0)*(VISC / DENS)**2)
C
      VAIR  =  FVAIR(TIME)
      PSI  =  FPSI(TIME)
      GM  =  GAMMA * PI / 180.
      PS  =  PSI * PI / 180.
      W  =  1.5708 - ASIN( ABS( COS(GM)*SIN(PS) - COS(PS)*SIN(GM) ))
      WCAL  =  1.194 - SIN(W) - 0.194*COS(2.*W) + 0.368*SIN(2.*W)
C
C*************************************************************
C*     CALCULATION OF THE NUSSELT NUMBER FOR FREE CONVECTION
C*************************************************************
      GR  =  GBETA * (DIA**3) * ABS(TEMP-TAIR)
      A  =  LOG10(GR * PR)
      LNU  =  A0 + A1*A + A2*A**2 + A3*A**3
      NU  =  10.**LNU
C
      RE  =  VAIR * DIA * DENS / VISC
C
      IF (RE .LT. 100.0) RE = 100.0
C
C*************************************************************
C*     CALCULATION OF THE NUSSELT NUMBER FOR FORCED CONVECTION
C*************************************************************
      LNU  =  B0 + B1*(LOG10(RE)) + B2*(LOG10(RE))**2
      NUO  =  10.**LNU
      NU2 = NUO * WCAL
C
C*************************************************************
C*      CALCULATION OF THE INTERPOLATED VALUE FOR THE
C*      NUSSELT NUMBER.
C*************************************************************
```

```
      IF ((NU2 .GT. NU) .AND. (RE .EQ. 100.0)) THEN
          S  = (NU2 - NU) / 100.0
          RE  =  VAIR * DIA * DENS / VISC
          NU  =  S * RE  +  NU
          GO TO 90
      ENDIF
C
      IF (NU2 .GT. NU) THEN
         NU = NU2
      ENDIF
C
C*************************************************************************
C*      CALCULATION OF THE HEAT TRANSFER COEFFICIENT
C*************************************************************************
   90 HTC  =  NU * K / DIA
C
      END
```

FUNCTION QROUT

Purpose: This function subprogram calculates the rate of radiant energy that it transferred from a unit length of conductor to the surroundings.

Input: TIME: Local time which, in turn, is used to calculate the local ambient air temperature

TEMP: The conductor temperature in ^{o}C

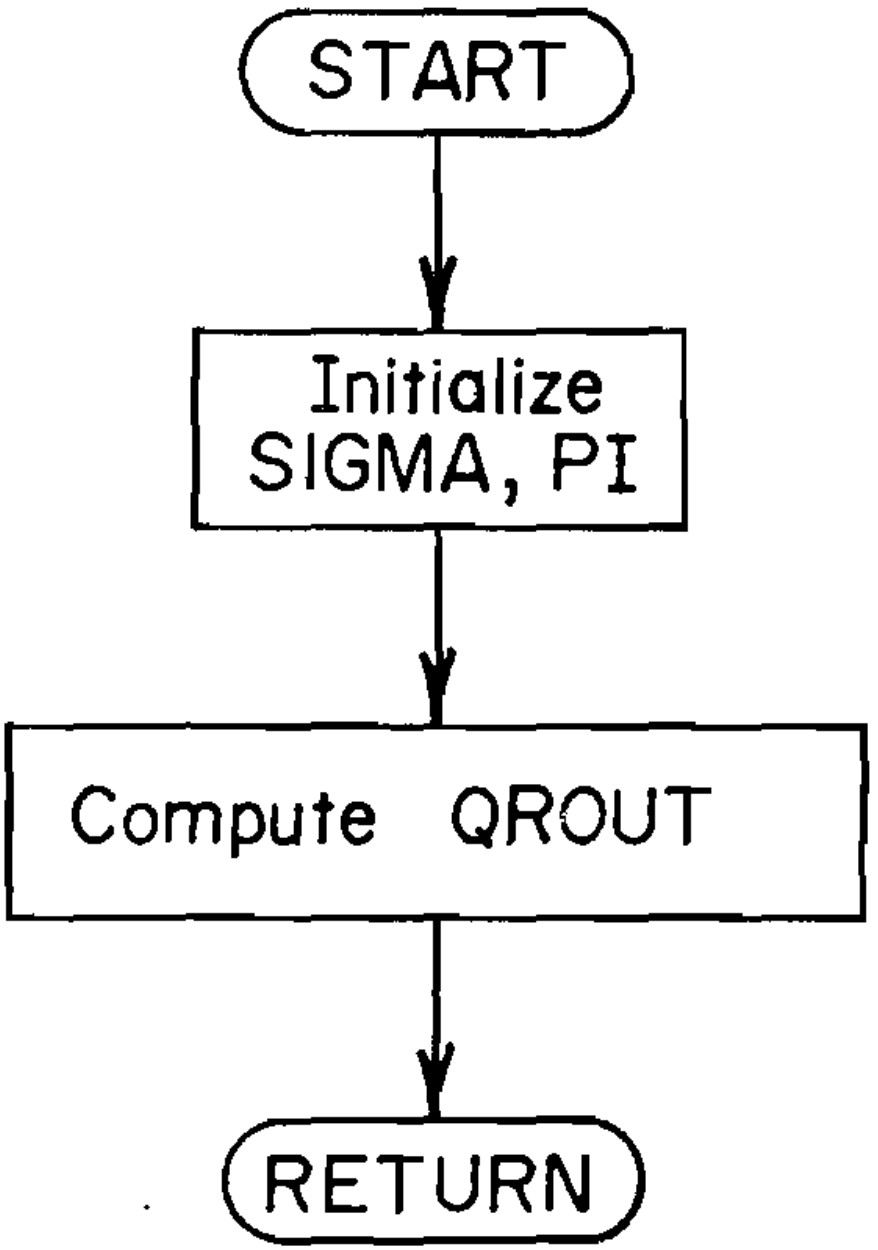
Output QROUT: Net radiant energy leaving a unit length of conductor in W/m.

Common Blocks:

Computer Symbols and Description of Variables:

Symbol	Description	Units
DIA	Outside diameter of conductor	m
EPSILN	Emissivity of conductor	
SIGMA	Stefan-Boltzmann constant	$W/m^2\ K^4$
TEMP	Conductor temperature	^{o}C
TINF	Subroutine that calculates ambient air temp.	^{o}C

FUNCTION QROUT



```
      FUNCTION QROUT(TIME,TEMP)
C*************************************************************
C*       THIS FUNCTION SUBPROGRAM CALCULATES THE RATE OF RADIANT
C*      HEAT TRANSFER FROM A UNIT LENGTH OF CONDUCTOR
C*      TO THE SURROUNDING IN WATTS PER METER.
C*************************************************************
      COMMON /BROUT/ EPSILN
     C       /BDIA/ DIA, Z
C
      PARAMETER (SIGMA = 5.67E-08, PI = 3.14159)
C
      QROUT = PI * EPSILN * SIGMA * DIA *((TEMP + 273.15)**4
     C         -(TINF(TIME) + 273.15)**4)
C
      END
```

FUNCTION RAC

Purpose: This function subprogram calculates the A.C. resistance for a unit length of conductor. The program considers ACSR, ACAR, solid copper conductors and copper conductors reinforced with a steel core.

Input: TEMP: the temperature of the conductor in ^{o}C.

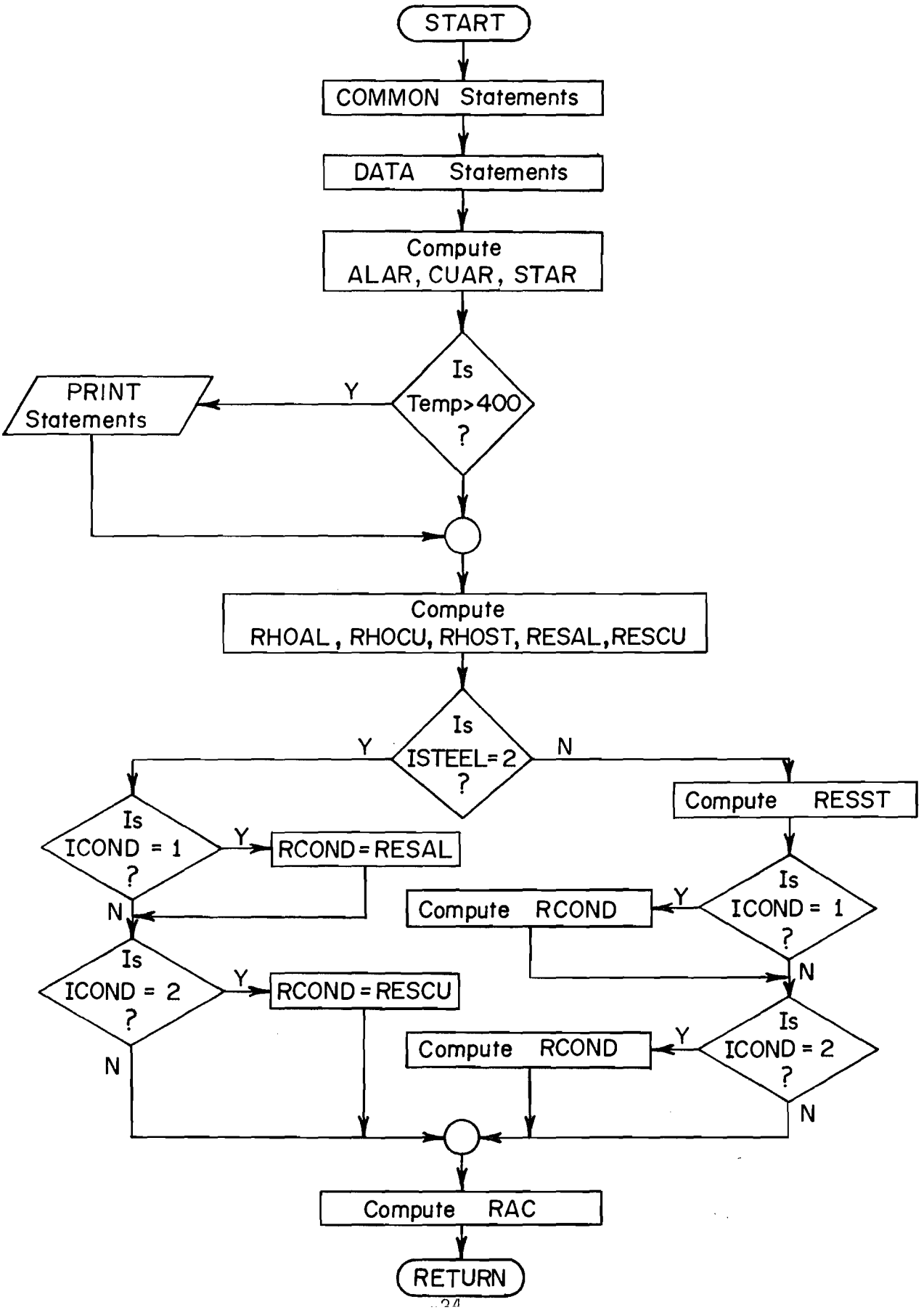
Output: RAC: the AC resistance of a unit length of conductor in ohms/cm.

Common Blocks:

Computer Symbols and Description of Variables:

Symbol	Description	Units
AAL,ACU,AST	Constants relating to the electrical resistivity of aluminum, copper and steel as a function of temperature	ohm $cm/^{o}C^{2}$
ARAL	Cross-sectional area of the aluminum conductor	cm^{2}
ARCU	Cross-sectional area of the copper conductor	cm^{2}
ARST	Cross-sectional area of the steel conductor	cm^{2}
BAL,BCU,BST	Constants relating to the electrical resistivity of aluminum, copper and steel as a function of temperature	ohm $cm/^{o}C$
CAL,CCU,CST	Constants relating to the electrical resistivity of aluminum, copper and steel as a function of temperature	ohm cm
INTOCM	Conversion factor between inches and cm	
MAXTEMP	Maximum limiting temperature for which calculations are valid	^{o}C
MINTEMP	Minimum limiting temperature for which calculations are valid	^{o}C
RCOND	Electrical resistance of a unit length of the composite conductor	ohm/cm
RESAL	Resistance of a unit length of aluminum conductor	ohm/cm
RESCU	Electrical resistance of a unit length of copper conductor	ohm/cm
RESST	Electrical resistance of a unit length of steel conductor	ohm/cm
RHOAL	Electrical resistivity of the aluminum conductor	ohm cm
RHOCU	Electrical resistivity of the copper conductor	ohm cm
RHOST	Electrical resistivity of the steel conductor	ohm cm

FUNCTION RAC



```
      FUNCTION RAC (TEMP)
*****************************************************************
*  THIS FUNCTION SUBPROGRAM CALCULATES THE A.C. RESISTANCE FOR FOUR *
*  DIFFERENT CONDUCTOR TYPES : ACSR, ACAR, COPPER CONDUCTOR STEEL-  *
*  REINFORCED AND SOLID COPPER CONDUCTOR. THE A.C. RESISTANCE IS    *
*  CALCULATED IN OHM / CM AND THE ONLY INPUT TO THE FUNCTION IS     *
*  THE TEMPERATURE IN DEG C .                                       *
*****************************************************************
      COMMON /BRES/ DAL, DCU, DST, STRAL, STRCU, STRST, SKIN
     C       /BSTO/ RMST, RMCOND, ICOND, ISTEEL

      PARAMETER (AAL = 4.716E-12, BAL = 1.1685E-08, CAL = 2.62E-06)
      PARAMETER (ACU = 7.396E-13, BCU = 7.049E-09, CCU = 1.5793E-06)
      PARAMETER (AST = 4.0500E-11, BST = 6.9068E-08, CST = 1.8149E-05)
      PARAMETER (PI = 3.14156, INTOCM = 2.54, TMAX = 400.0, TMIN =-50.0)
*****************************************************************
*  CALCULATION OF THE AREAS OF EACH CONDUCTOR                       *
*****************************************************************
      ARAL = PI * STRAL * (((DAL / 2.0) * INTOCM)**2)
      ARCU = PI * STRCU * (((DCU / 2.0) * INTOCM)**2)
      ARST = PI * STRST * (((DST / 2.0) * INTOCM)**2)
*****************************************************************
*  WARNING STATEMENTS FOR INVALID TEMPERATURE DATA                  *
*****************************************************************
      IF ((TEMP .GT. TMAX) .OR. (TEMP .LT. TMIN)) THEN
         PRINT 44,' TEMP IS OUT OF RANGE OF RESISTIVITY EQUATIONS'
         PRINT 22, ' SINCE TEMPERATURE IS ', TEMP, ' DEG C'
22       FORMAT (1X, A, F5.1, A)
         PRINT 44, ' HOWEVER, CALCULATIONS WILL CONTINUE'
44       FORMAT (2X, A)
      END IF
         RHOAL = AAL * TEMP**2 + BAL * TEMP + CAL
         RHOCU = ACU * TEMP**2 + BCU * TEMP + CCU
         RHOST = AST * TEMP**2 + BST * TEMP + CST
         RESAL = RHOAL / ARAL
         RESCU = RHOCU / ARCU
*****************************************************************
  CHECK FOR PURE  OR STEEL-REINFORCED CONDUCTOR                    *
*****************************************************************
      IF (ISTEEL .EQ. 2) THEN
         IF (ICOND .EQ. 1) RCOND = RESAL
         IF (ICOND .EQ. 2) RCOND = RESCU
      ELSE
         RESST = RHOST / ARST
         IF (ICOND .EQ. 1) RCOND = (RESST * RESAL) / (RESST + RESAL)
         IF (ICOND .EQ. 2) RCOND = (RESST * RESCU) / (RESST + RESCU)
      END IF

      RAC = RCOND * SKIN

      END
```

FUNCTION RMCP

Purpose: This subprogram calculates the product of the conductor mass per unit length and the specific heat of the conductor as a function of the conductor temperature

Input: TEMP: the conductor temperature in ^{o}C

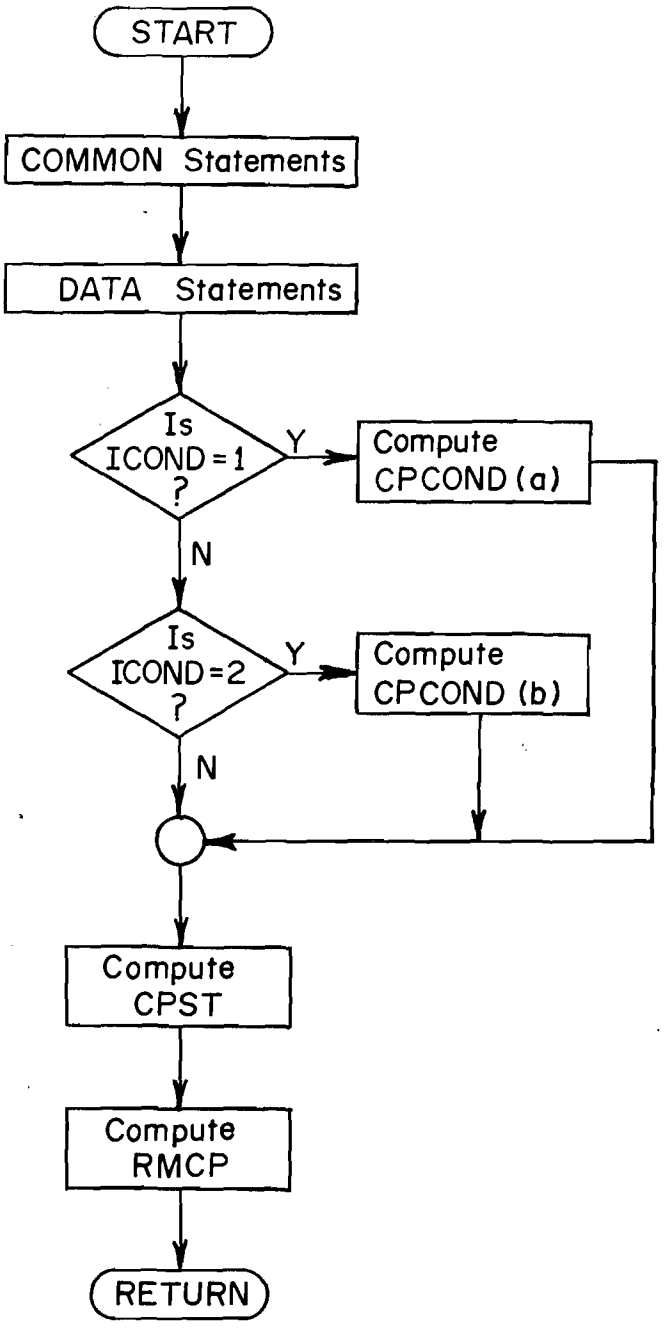
Output: RMCP: the product of conductor mass per unit length and specific heat in $J/cm^{o}C$.

Common Blocks:

Computer Symbols and Description of Variables:

Symbol	Description	Units
CPCOND	Specific heat at constant pressure for the conductor	J/kg K
CPST	Specific heat at constant pressure for the steel	J/kg K
RMST	Mass per unit length of steel	kg/m

FUNCTION RMCP



```
      FUNCTION RMCP (TEMP)
*********************************************************************
*  THIS FUNCTION SUBPROGRAM CALCULATES THE PRODUCT OF THE CONDUCTOR *
* MASS PER UNIT LENGTH WITH THE SPECIFIC HEAT AS A FUNCTION OF THE  *
* CONDUCTOR TEMPERATURE(TEMP) IN DEG C . THE RESULT IS IN JOULES    *
* PER CM DEG C .                                                    *
*********************************************************************
      COMMON /BSTO/ RMST, RMCOND, ICOND, ISTEEL

      PARAMETER (CONST1 = 0.32236, CONST2 = 0.02512, CONST3 = 0.47517)
      PARAMETER (CONST4 = 929.4, CONST5 = 422.0, CONST6 = 441.0)

      IF (ICOND .EQ. 1) THEN
         CPCOND = CONST1 * TEMP + CONST4
      ELSE IF (ICOND .EQ. 2) THEN
         CPCOND  = CONST2 *  TEMP + CONST5
      END IF

      CPST = CONST3 * TEMP + CONST6

      IF (ISTEEL .EQ. 2) THEN
         CPST = 0.0
      END IF
*********************************************************************
*  COMPUTE RMCP AND RETURN ITS VALUE TO MAIN .                      *
*********************************************************************
      RMCP = RMST * CPST + RMCOND * CPCOND

      END
```

FUNCTION YINT

Purpose: This subprogram provides interpolated values within an ordered array of tabulated data.

Input:
- X: an array of N data values
- Y: an array of N data values
- N: an integer value equal to the number of ordered X and Y values
- M: order of interpolation (i.e. M = 2, for linear interpolation; M = 3 for parabolic interpolation, etc.)
- P: value for X at which interpolated Y is desired

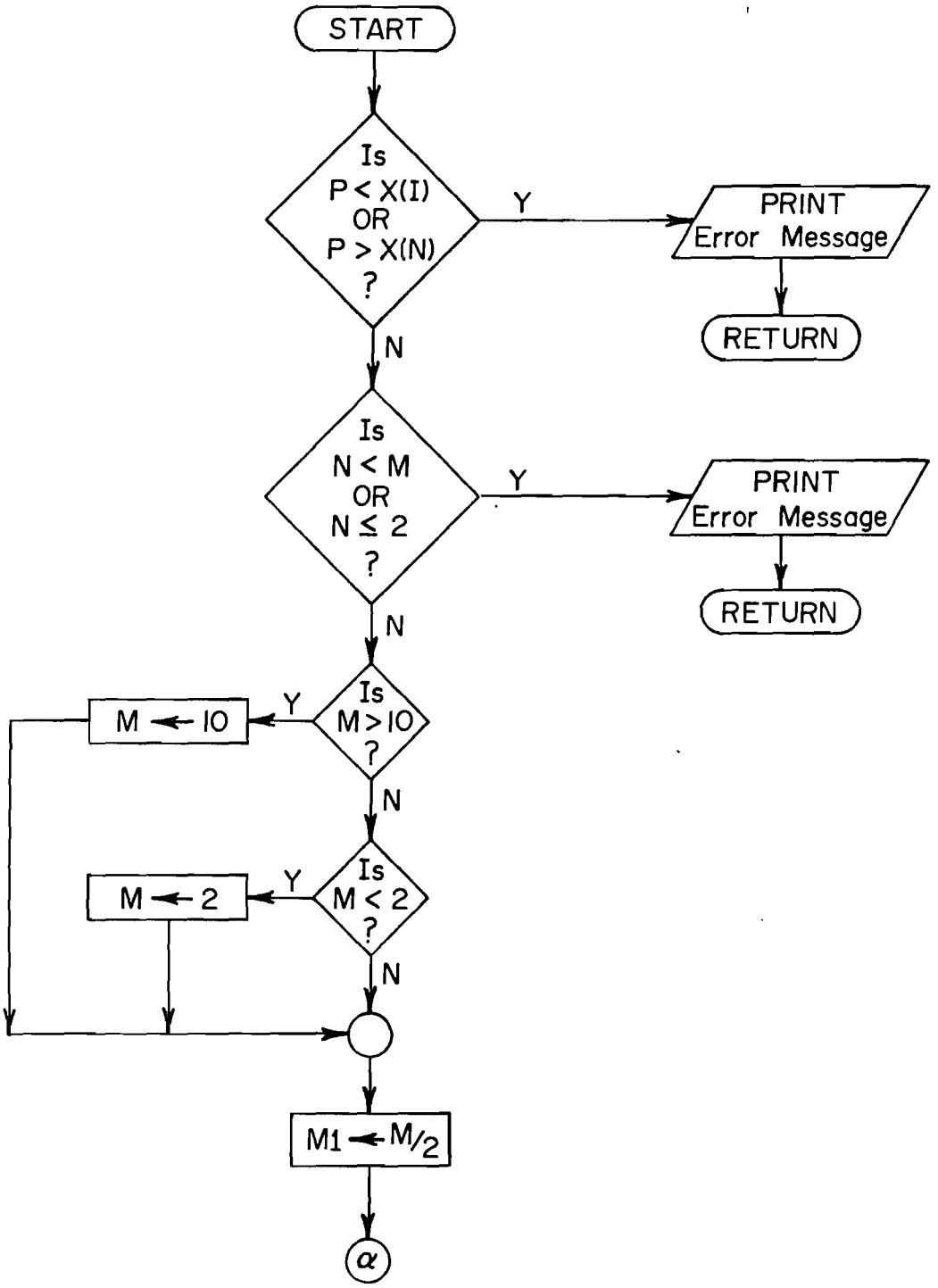
Output: YINT: the interpolated value for Y at the X value equal to P.

Common Blocks:

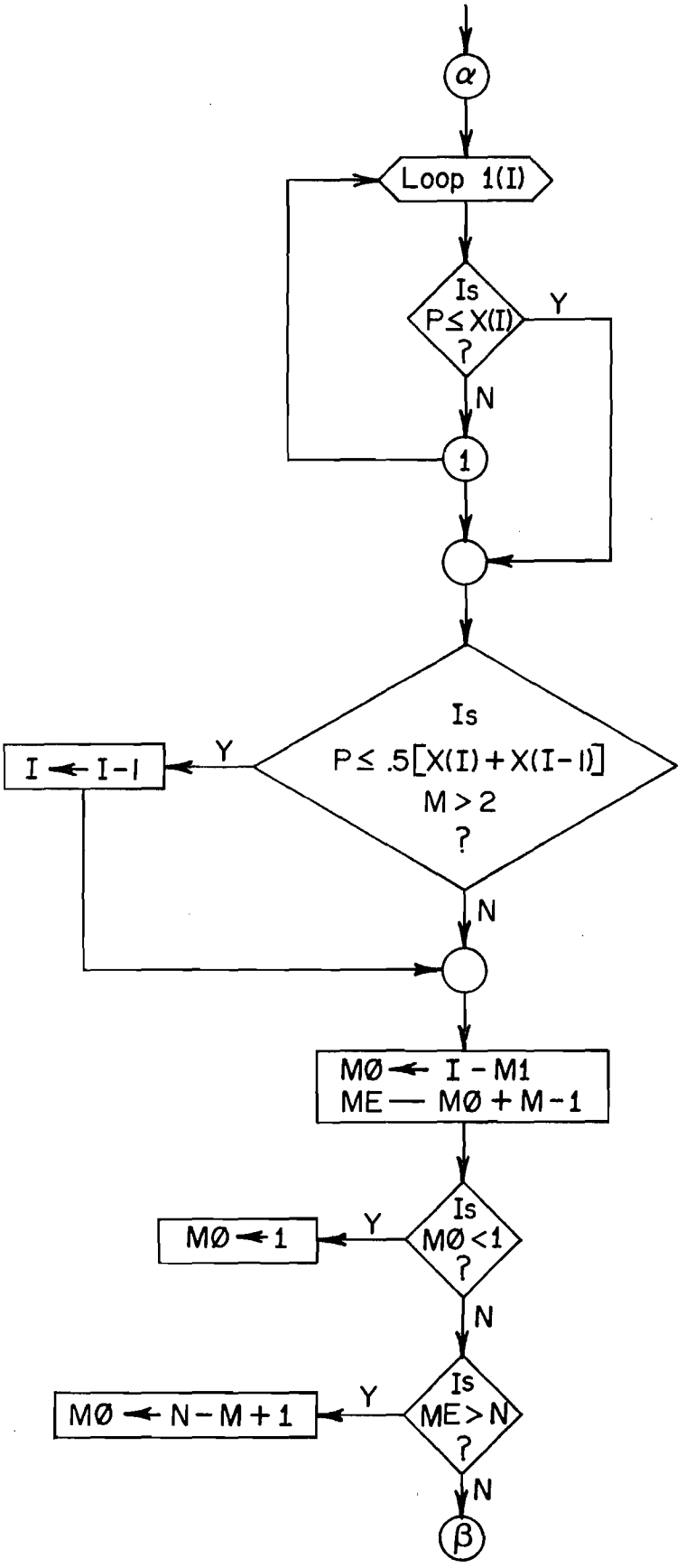
Computer Symbols and Description of Variables:

Symbol	Description	Units
I,J	Variables used as counters	
L	Variables used as counters or	
MO		
M1	Half the order of interpolation	
M	The order of interpolation	
ME	subscripts	
N	Number of data points	
P	X value at which interpolation for the Y-value is desired	
X	The x-coordinate variable	
XP	manipulations	
XQ		
XX	Variables used in the interpolation	
Y	The y-coordinate variable	
YY		

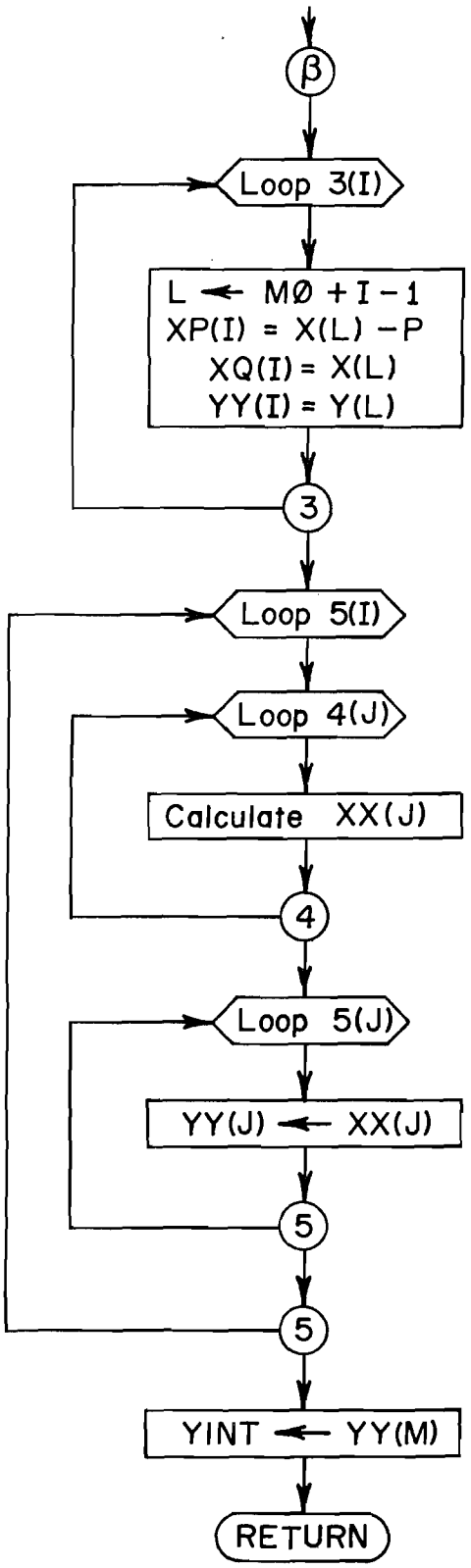
FUNCTION YINT



FUNCTION YINT (cont.)



FUNCTION YINT (cont.)



```
      FUNCTION YINT(X, Y, N, M, P)
************************************************************************
*  THIS FUNCTION SUBPROGRAM IS USED TO INTERPOLATE WITHIN A SET      *
* OF TABULAR VALUES .                                                *
************************************************************************
      DIMENSION X(N), Y(N), XX(10), XP(10), XQ(10), YY(10)

      IF (P .LT. X(1) .OR. P .GT. X(N)) THEN
         WRITE (7, 9) P
         RETURN
      END IF

      IF (N .LT. M .OR. N .LE. 2) THEN
         WRITE (7, 7)
         RETURN
      END IF

 7    FORMAT (/, 44HINTERPOL. IS IMPOSIBLE, DATA ARRAY TOO SMALL)
 9    FORMAT (/, 29HINTERPOL. IS IMPOSSIBLE, P = , E12.4,
     C        12HOUT OF RANGE)

      IF (M .GT. 10) THEN
         M = 10
      ELSE IF (M .LT. 2) THEN
         M = 2
      END IF

      M1 = M / 2
      DO 1 I = 1, N
      IF (P .LE. X(I)) GO TO 2
1     CONTINUE
2     IF (P .LE. 0.5 * (X(I) + X(I - 1)) .AND. M .GT. 2) THEN
         I = I - 1
      END IF

      M0 = I - M1
      ME = M0 + M - 1

      IF (M0 .LT. 1) THEN
         M0 = 1
      ELSE IF (ME .GT. N) THEN
         M0 = N - M + 1
      END IF

      DO 3 I = 1, M
      L = M0 + I - 1
      XP(I) = X(L) - P
      XQ(I) = X(L)
3     YY(I) = Y(L)

      DO 5 I = 2, M
         DO 4 J = I, M
         XX(J) = (YY(I - 1) * XP(J) - YY(J) * XP(I - 1)) /
     C           (XQ(J) - XQ(I - 1))
4        CONTINUE
         DO 5 J = 1, M
         YY(J) = XX(J)
```

```
5       CONTINUE

        YINT = YY(M)

        END
```

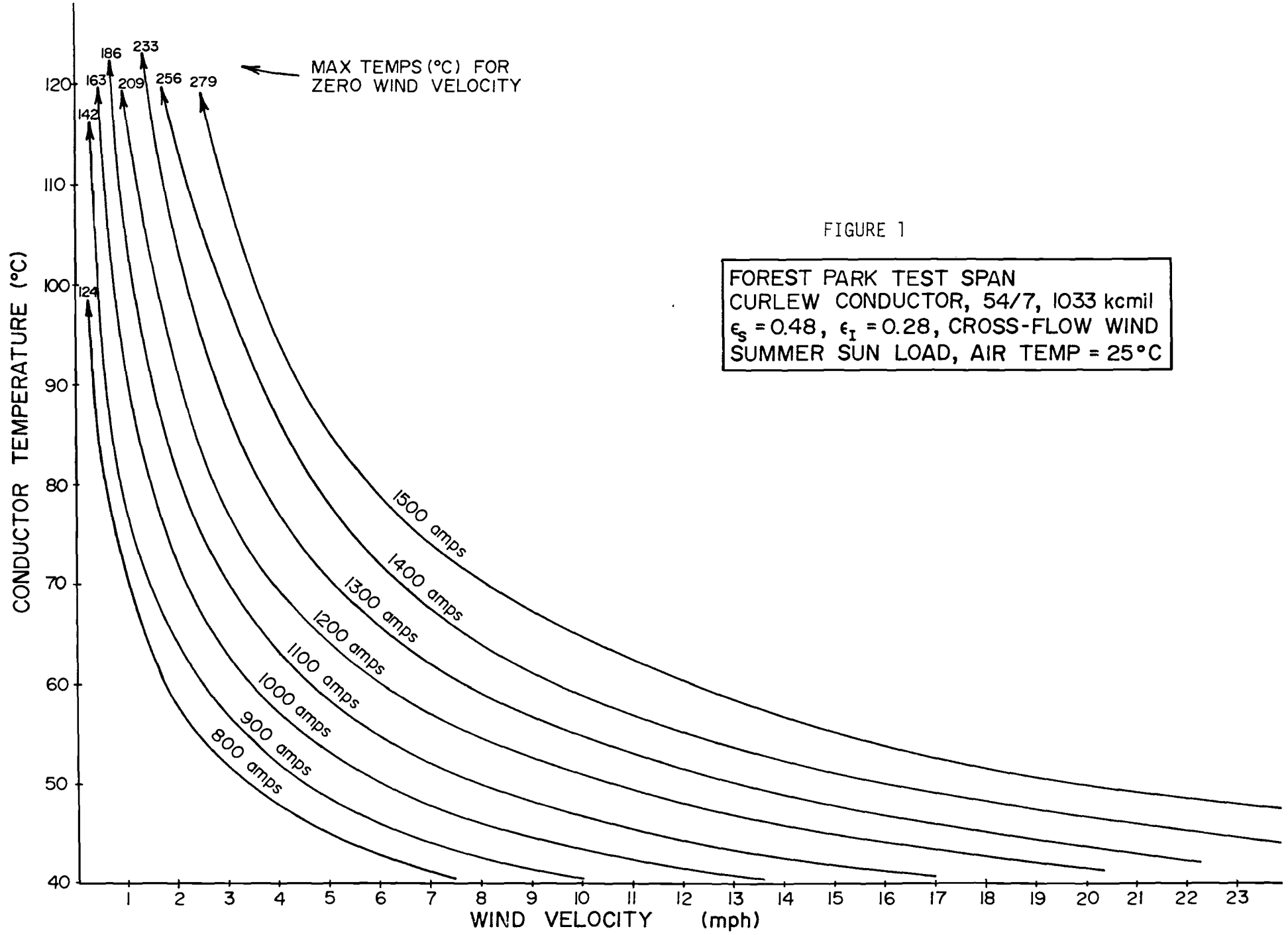


FIGURE 1

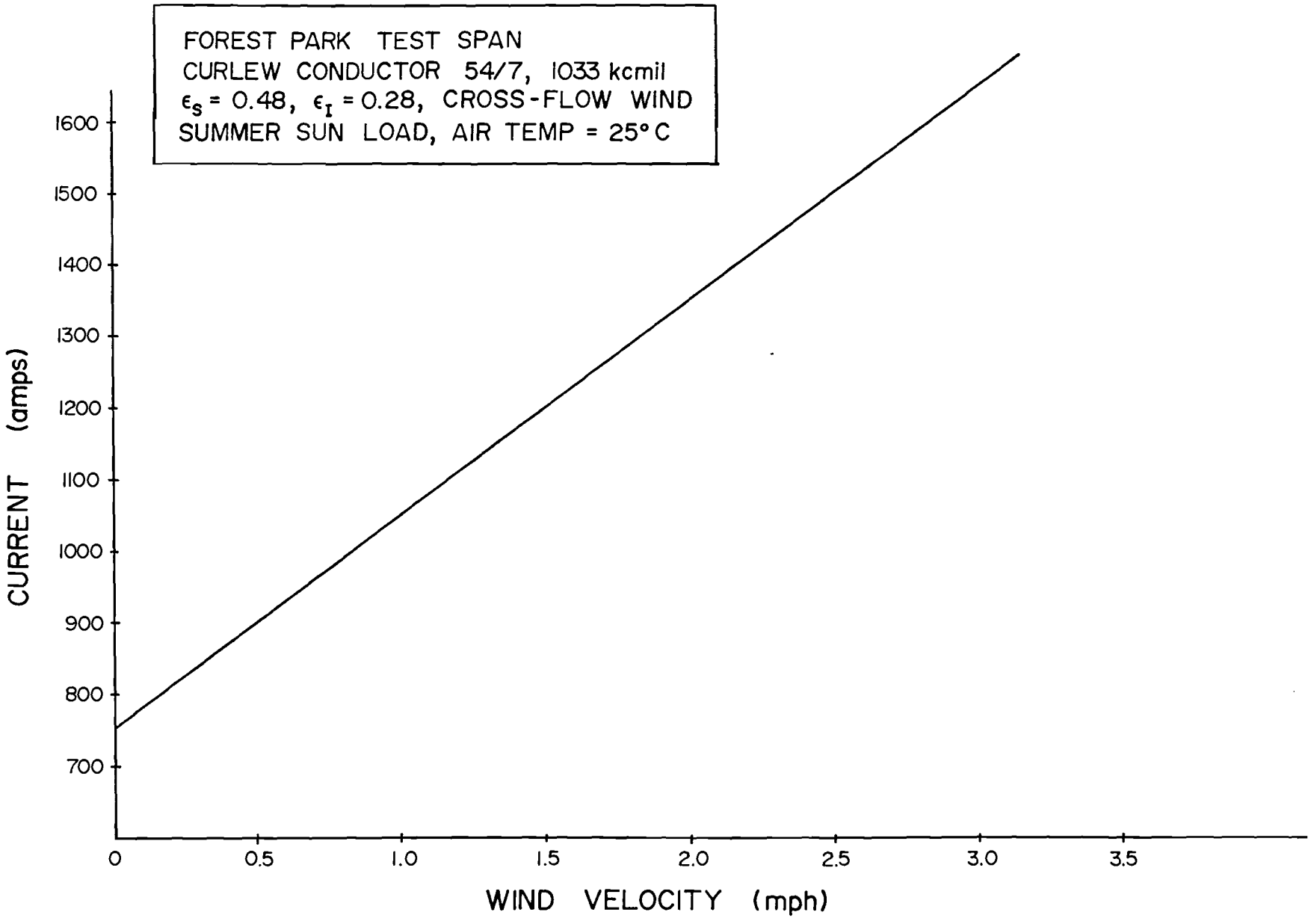
FOREST PARK TEST SPAN
CURLEW CONDUCTOR, 54/7, 1033 kcmil
$\epsilon_s = 0.48$, $\epsilon_I = 0.28$, CROSS-FLOW WIND
SUMMER SUN LOAD, AIR TEMP = 25°C

V. FOREST PARK TEST SITE WORK (Task 3)

A decision has been reached to make both hardware and software modifications in the existing weather data acquisition system located at the Forest Park test facility. The weather station hardware will be modified to allow for polling of the weather station by the system control computer. Currently, the weather station sends data at one minute intervals. The system control computer must continually monitor the data link to intercept the incoming data. The proposed hardware modification will allow the control computer to request data from the weather station as needed thereby freeing the control of all incoming data to magnetic tape and eliminating the need to manually key in line data when running the thermal modeling program. The proposed software changes are necessary to handle the magnetic recording of data and to provide an "averaged" wind speed for the proposed five minute sampling interval.

Initial plans have been made to select a larger conductor for the Forest Park test facility. Although additional calculations are still necessary to verify final equipment modifications, a preliminary analysis indicates a 1033 ACSR conductor will meet both the requirement and the physical constraints of the existing system proposed at the project "kick-off" meeting held in Atlanta. Final design calculations should be completed by the end of the year. A summary of the ampacity curves provided by the dynamic thermal line program for a 1033 ACSR conductor are shown in Figures 1 and 2. Factors affecting the specific conductor choice will be (1) maximum anticipated conductor temperature during the test program, (2) expected "average" weather conditions in the Atlanta area during the period of system operation, (3) stranding of the test conductor, and (4) power limitations imposed by the existing line driving and impedance matching equipment.

FIGURE 2



CURRENT NECESSARY TO PRODUCE A CONDUCTOR TEMPERATURE OF 120° C

Several proposed design changes have been considered to minimize lightning susceptability at the Forest Park Facility. During the last week of October John Czuba of Power Technologies, Inc. visited the Atlanta site for the purpose of making recommendations to minimize lightning susceptability of the existing test facility. To date a written report has not been submitted, but discussions after the site inspection indicate several areas in which improvements can be made. These areas are: (1) make the thermocouple shielding continuous from the point of measurement to the data acquisition system, (2) install all instrumentation in steel conduit, (3) run all instrumentation conductors in close proximity to the test conductor, and (4) use fiber optic data transmission where possible. Suggestions 1, 3 and 4 will be implemented. The cost and difficulty of implementing suggestion 2 are currently felt to be prohibitive relative to the anticipated gain in system reliability. Specific tasks to be accomplished include (1) replacing the existing thermocouple extension wire from the test points to the junction box at the end of the test span, (2) suspending the thermocouple wire from either the test conductor or a span guy in close proximity to the test conductor, (3) changing the shield grounding on the thermocouples to tie through at the thermocouple junction box, and (4) replacing a hard wire analog data link with an equivalent fiber optic cable. Replacement of the thermocouple extension wire is necessary due to "dig in" damage to the existing buried conductors and to clear construction which is currently in progress under the test span.

The accuracy of the ampacity program is directly dependent upon the accuracy of the weather data that is used as input to the program. The utility survey indicates that very few companies have the capability to monitor weather conditions and many utilities may be forced to resort to weather data that is collected miles from the location of the transmission

lines. To check the accuracy of the program when weather data is collected at a remote weather station, initial plans have been made to obtain weather data from the Atlanta airport which is approximately five miles from the Forest Park facility. Both weather data from the airport and weather parameters measured by the station located at the test site will be put into the program and the differences in predicted conductor temperatures will be used to assess the influence on the accuracy of the ampacity program.

A review of commercially available on-line conductor monitors is in progress. Monitors will be obtained for installation on the transmission span in Forest Park. The Linfo Line Monitor manufactured in Sweden has been ordered by Georgia Power for installation at the site. This device is being loaned for the duration of the EPRI project. A Thermo-Tector manufactured by A. B. Chance has been purchased. This inexpensive device is held with a hot stick against an energized overhead line. The temperature is read from an LCD display mounted on the device. Negotiations are underway to purchase line monitors offered by Creative Power Systems and Niagara Mohawk. These systems require the use of radio signals to transmit data.

APPENDIX

COPY OF UTILITY SURVEY

UTILITY SURVEY
CONDUCTOR TEMPERATURE RESEARCH
EPRI PROJECT 2546

INTRODUCTION

Georgia Institute of Technology and Georgia Power Company are currently developing a real-time ampacity model for overhead conductors under the sponsorship of EPRI Project 2546. An initial phase of this project involves surveying several representative utilities who will ultimately utilize the ampacity model on their operating systems. The purpose of this survey is to provide utility input in the early stages of the model design and to provide direction to the model so that it receives the greatest possible utilization by the Transmission and Distribution engineer.

The survey is separated into four sections. Section I deals with your particular transmission network. Section II asks questions relating to how your utility handles the steady state ratings of your system. Section III concerns the capability your utility has for rating conductors on a real-time basis. Section IV considers the problem of monitoring conductor temperatures with instrumentation and the identification of critical spans.

A response should be given to all questions. If a particular question could be answered one way by, say, an operating engineer and another way by a design engineer, be sure to enter both answers and identify the individual responsible for each answer. Responses to all questions will be compiled and a summary of the results will be provided in the final report to EPRI. A copy of the final report will be made available to participants.

Thank you for your participation in this important project. Your responses to these questions are important in forming the framework of the ampacity program.

If you have difficulty in interpreting or answering any of the questions, please contact W. Z. Black at (404) 894-3257.

7/84

rev. 9/84

Date: _____

Name: _____

Position/Title: _____

Company Affiliation: _____

Address: _____

Telephone: _____

SECTION I

Operation of Your Transmission and Distribution System

1. List the principal bare overhead conductor sizes you use on your system

Designation eg. Drake, Linnet	Type ACSR,ACAR,etc.	kcmil Area	Stranding	kV

Comments: _____

_____

_____

_____

8. For the following parameters your preference for units are:

Conductor area	kcmil ☐	cm^2 ☐
Mass of conductor	lb/ft ☐	kg/m ☐
Strand diameter	in. ☐	cm ☐
O.D. of conductor	in. ☐	cm ☐
Temperature	^oF ☐	^oC ☐
Wind Velocity	ft/s ☐	m/s ☐
	mi/hr ☐	km/hr ☐
Resistance	ohms/1000ft ☐	ohms/m ☐

5. Does your steady ampacity model consider incident solar energy on the conductor? Yes ☐ No ☐

   If yes, what is the value for solar energy? Does it change with season or with geographical location?

   _____

   _____

   _____

6. Do you consider the direction of the conductor when considering the influence of sun on the conductor temperature? Yes ☐ No ☐

7. What values of infrared emissivity and solar absorptivity do you use in your ampacity model? ε_I = _____ α_s = _____

8. Do you consider only a single wind velocity in your steady ampacity model? Yes ☐ No ☐

   If yes, what is the value? V = _____ ft/sec

   If no, what is the minimum and maximum value for wind velocity and what dictates the selection between the two values? V_{max} = _____ ft/sec

   V_{min} = _____ ft/sec

   _____

   _____

   _____

9. Do you assume the wind is always oriented perpendicularly to the conductor? Yes ☐ No ☐

   If no, what is the angle of wind relative to the axis of the conductor? θ = _____ degrees

10. Do you calculate conductor ratings for:

	Yes	No
Normal Conditions	☐	☐
Emergency Operation	☐	☐
Fault Conditions	☐	☐

    If yes, for emergency operation and fault conditions give estimates for time that you would expect ampacity values to be valid

    Emergency time = _____ min

    Fault time = _____ min

11. Does your steady ampacity model consider the following factors:

	Yes	No
Magnetic heating?	☐	☐
Temperature gradient in the conductor?	☐	☐
Evaporative cooling?	☐	☐

12. How is your ampacity information made available to your operating personnel (those who run the system on a daily basis):

	Yes	No
CRT display?	☐	☐
Tables?	☐	☐
Standards Manual?	☐	☐
Other, specify?	☐	☐

_____

_____

_____

13. What are the maximum conductor temperatures your company considers for the following conditions:

Normal?	T= ____ ^{o}C
Emergency?	T= ____ ^{o}C
Fault?	T= ____ ^{o}C

If you have different ratings for different conductors give ratings and basis for different ratings

_____

_____

_____

14. Are the limitations for the maximum operating temperature dictated by:

	Yes	No
Clearance?	☐	☐
Loss of strength?	☐	☐
Creep?	☐	☐
Degradation of terminations, splices?	☐	☐
Economic?	☐	☐
Other, specify?	☐	☐

_____

_____

_____

SECTION III

Real-Time Ampacity Calculations

1. Does your company at the present time have the ability to predict the real-time rating of your overhead system? Yes ☐ No ☐

   If no, would you consider implementing a real-time rating program if it were available? Yes ☐ No ☐

2. Where do you feel the greatest application a real-time rating system would have within your company?
   Planning ☐
   Operations ☐
   Design ☐

3. If a real-time conductor temperature program were available, how accurate would it have to predict the conductor temperature before you would consider using it?
   ±1°C ☐ ±5°C ☐ ±10°C ☐ ±20°C ☐

4. What is the priority of a real-time ampacity program within your transmission and distribution division?
   High ☐
   Moderate ☐
   Low ☐

5. If a real-time rating program were available, state the type of computing equipment your company would use to implement the program.
   ☐ mainframe
   ☐ personal computer
   ☐ both
   ☐ neither

6. Give important factors that should be used in providing information from a real-time ampacity model.

	Yes	No
Simplicity?	☐	☐
Ability to handle all types of conductors and all possible weather conditions?	☐	☐
Completeness of information?	☐	☐
Others, specify?	☐	☐

_____

_____

_____

7. How should information from a real-time ampacity program be conveyed to the user:

	Yes	No
A conductor time constant?	☐	☐
A time required to reach a predetermined limiting temperature?	☐	☐
A set of curves that predict temperature vs. time behavior of the conductor?	☐	☐
Other, specify?	☐	☐

SECTION IV

Ampacity Instrumentation and Critical Span Analysis

1. Does your company at the present time measure the conductor temperature on any of its energized lines? Yes ☐ No ☐

   If yes, how many instruments are installed?

   _____

   _____

   _____

   If yes, what type of instrumentation do you use: made in-house, or manufactured by others? Briefly describe these devices?

   _____

   _____

   _____

2. Does your company have any future plans to install temperature measuring devices on energized lines? Yes ☐ No ☐

3. Does your company utilize the concept of a "critical span" in determining the real-time rating of its network? Yes ☐ No ☐

   If yes, how does your company define a critical span?

   _____

   _____

   _____

   If yes, do you consider a critical span to vary from one location to another as weather and operating conditions vary or does the location remain constant?

   _____

   _____

   _____

4. What criteria would you use in selecting a location to install a limited number of line temperature monitors:

	Yes	No
Locations known to have thermal problems in the past	☐	☐
Locations on "critical spans"	☐	☐
A critical span on a line that is experiencing exceptional load growth	☐	☐
Other locations, specify	☐	☐

_____

_____

_____

5. If reliable line monitoring equipment were readily available in the range of $10,000-$15,000, would you consider installing it on your system?

Yes	No
☐	☐

If yes, approximately how many devices would you install?

_____

_____

_____

QUARTERLY PROGRESS REPORT

EPRI PROJECT 2546

CONDUCTOR TEMPERATURE RESEARCH

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Atlanta, Georgia 30332

and

Georgia Power Company
Research Center

New Orleans

February 1, 1986

NOTICE

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I. EXPERIMENTAL PHASE

During the past six months the experimental phase of the project has progressed satisfactorily. The test span operated by Georgia Power Company and located at their Research Center in Forest Park has continued to collect weather data, conductor currents and conductor temperatures. Since the last report, the test span was operated for nearly 50 days. In addition, weather data has also been collected at four weather stations located between 1 mile and 25 miles from the test span. This phase of the experimental work is summarized in Section B. Finally a separate phase of the experimental work funded by KEURP was carried out by Kansas Gas and Electric. A line monitor initially used at the Forest Park test span was calibrated and sent to Kansas. There it was installed at four different sites on four different conductor sites. The results of this work is reported in Section C.

A. Operation of the Forest Park Test Span

Since the last report presented in late July at Idaho Power Company, the Forest Park test span has been operated for nearly 50 days. The times of operation are listed in Table 1. With the exception of a few minor outages, the operation of the line and the data collection system has been routine. At this time the test line has been partially disassembled and the collection of weather data and conductor temperatures at the test span is now complete.

TABLE 1. DATA COLLECTION LOG

DATE	CURRENT	O.H. LINE	REMOTE #1 HV LAB	REMOTE #2 S. DEKALB	REMOTE #3 CONYERS	REMOTE #4 SHENANDOAH
6-16-86	1200	10:54-23:55	---			
6-17-86		0:00-23:55	8:30-23:55			
6-18-86		0:00-00:17	0:00-09:20			
6-19-86		17:02-23:55	12:05-23:55			
6-20-86		0:00-15:23	0:00-15:25			
6-21-86		---	---			
6-22-86		---	---			
6-23-86	1200	8:29-23:55	---			
6-24-86*		0:00-23:55	11:35-23:55	0:00-23:55	0:00-23:55	0:00-23:55
6-25-86*	1400	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
6-26-86*	1000	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
6-27-86*	800	0:00-23:55	0:00-08:55	0:00-23:55	0:00-23:55	0:00-23:55
	1100		9:05-23:55			
6-28-86*		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
6-29-86		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
6-30-86*	1200	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
	1400					
7-01-86*	1200	0:00-23:55	0:00-13:40	0:00-23:55	0:00-23:55	0:00-23:55
			14:00-23:55			
7-02-86*		0:00-06:22	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
		13:58-23:55				
7-03-86*		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
7-04-86*	1000	0:00-23:55	0:00-19:00	0:00-23:55	0:00-23:55	0:00-23:55
			19:20-23:55			
7-05-86*		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
7-06-86		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
7-07-86*	0	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
7-08-86*	800	0:00-23:55	0:00-10:00	0:00-23:55	0:00-23:55	0:00-23:55
			10:10-23:55			
7-09-86*		0:00-23:55	0:00-14:10	0:00-23:55	0:00-23:55	0:00-23:55
7-10-86		0:00-17:33	---	0:00-23:55	0:00-23:55	0:00-23:55
7-11-86		6:24-23:55	16:00-21:55	0:00-23:55	0:00-23:55	0:00-23:55
7-12-86*		0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55	0:00-23:55
7-13-86*		0:00-23:55	0:00-16:55	0:00-23:55	0:00-23:55	0:00-23:55
			17:05-23:55			
7-14-86		0:00-06:56	0:00-23:55	0:00-23:55	0:00-23:55	0:00-22:50
7-15-86		---	0:00-23:55			
7-16-86	1200	6:47-23:55	0:00-13:20			
7-17-86		0:00-20:09	0:00-23:55			
7-18-86*		6:37-23:55	0:00-23:55			
7-19-86*		0:00-23:55	0:00-23:55			
7-20-86		0:00-18:56	0:00-23:55			
7-21-86		---	0:00-19:30			
7-22-86		6:33-23:55	9:00-23:55			
7-23-86*	800	0:00-23:55	0:00-23:55			
7-24-86*		0:00-23:55	0:00-23:55			
7-25-86*	1000	0:00-23:55	0:00-10:15			
			11:15-23:55			
7-26-86		0:00-16:29	0:00-23:55			
		16:53-23:55				
7-27-86		0:00-15:09	0:00-23:55			
		15:31-23:55				
7-28-86		0:00-21:55	0:00-23:55			
		22:16-23:55				
7-29-86	1100	0:00-12:55	0:00-08:10			
		17:17-23:55	8:20-23:55			
7-30-86		0:00-16:39	0:00-23:55			
		16:11-23:55				
7-31-86		0:00-06:37	0:00-23:55			
8-01-86		---	0:00-05:45			

B. Weather Data Collection at Remotes Sites

The utility industry has found little information available to guide the transmission engineer in positioning the data collection equipment necessary to implement a dynamic line rating system. Each utility is faced with different length transmission lines, unique weather conditions and varying terrain. Idaho Power, having a strong interest in EPRI project 2546, has contracted with Georgia Power Company through SEI to determine the effects of weather station site selection on line temperature predictions.

The existing transmission line test span used in the EPRI Project was operated for over two months while time, line current, conductor temperature, and weather conditions were recorded. Wind speed, wind direction, and ambient temperature were also recorded at four remote sites ranging from 1 to 25 miles away from the test site. The weather data from the remote sites was compared to the data from the test span. The recorded conductor current and weather data from each site were then used by DYNAMP to predict the temperature of the transmission line conductor based on weather data from each site. The computer predictions using data from each remote site were compared to the measured line temperatures.

Remote site number one was located one mile from the test span at the High Voltage Laboratory of the Research Center. This site was assembled from weather station sensors obtained from the Georgia Power Telecommunications Department, an Apple IIe computer system and HP data acquisition system belonging to the Research Center. The sensors were

installed on a 70 foot transmission pole. Cables were run into the High Voltage Lab where the computer and data acquisition system were located. Software was written to read the sensors once each minute and to average those readings for each five minute period. The data was printed and then stored in the input format of DYNAMP on the Apple IIe disk drive. The data was later transferred to an IBM PC over an RS-232 data link and stored on IBM compatible disks to be read directly by DYNAMP.

Remote site number two was located at the south campus of Dekalb Junior College. It was owned by the Department of Natural Resources of the State of Georgia. The data were recorded continuously on a strip chart recorder and averaged in fifteen intervals because the chart scale made it too difficult to obtain five minute averages. Personnel from the Research Center went to the office which stores these charts to visually average the data over 15 minute periods. The fifteen-minute averages were then entered into a portable IBM PC compatible computer which stored the data in the format of DYNAMP data files.

Remote site number three was located at the Trappist Monastery in Conyers, Ga. This facility, belonging to the Department of Natural Resources of the State of Georgia, was the only site where ambient temperature was not available. Wind speed and wind direction were recorded continuously on a strip chart recorder. The data was visually averaged over 5 minute periods then stored on disk in DYNAMP format.

Remote site number four was located at the Shenandoah Solar Center in Shenandoah, Georgia. This facility routinely monitors weather as

part of ongoing research for Georgia Power and Department of Energy projects. Weather data were sampled every twelve seconds and averaged for each minute. The one-minute averages were stored on tape by a DEC mini-computer. For this project, the one-minute averages were transferred to the Research Center using a modem. The data were then averaged for each five minute period by an IBM PC and sorted on diskettes in the DYNAMP format.

Table 2 is a summary of information gathered at each weather station. The equipment at all sites had been calibrated within three months when data collection began. Figures 1-5 contain sketches of all weather station sites showing the location of the sensors and surrounding objects which could affect the weather data. Table 1 gives the time periods that data was collected at the base station and at the four remote sites. The weather data from each site was read into the DYNAMP program to determine how well the predictions would match the line temperatures measured at the base station.

A typical set of data generated on June 30, 1986 is shown in Figures 6-10. Between 8:00 am and 6:00 pm (1800 hours) steady wind conditions prevailed and DYNAMP predicted line temperatures fairly accurately with weather data collected at stations up to twenty-five miles away from the base station.

After 6:00 pm the wind direction remained fairly steady but the wind speed decreased at all weather stations. The accuracy of the DYNAMP predictions began to fall using data from all sites farther than a few miles from the base station. Remote site 1 which is one mile from

TABLE 2. WEATHER STATION DESCRIPTIONS

	Overhead Line Research Center	Remote Site #1 High Voltage Lab	Remote Site #2 South Dekalb	Remote Site #3 Conyers	Remote Site #4 Shenandoah
Owner:	Georgia Power Co.	Georgia Power Co.	State of Georgia	State of Georgia	Georgia Power Co.
Location:					
Address	62 Lake Mirror Rd. Forest Park, Ga.	5351 Kennedy Rd. Forest Park, Ga.	3251 Panthersville Rd. Decatur, Ga.	2370 Ga. Hwy. 212 Conyers, Ga.	7 Solar Circle Shenandoah, Ga.
Latitude	33° 37' 25" N	33° 36' 29" N	33° 41' 26" N	33° 35' 8" N	33° 24' 17" N
Longitude	84° 23' 10" W	84° 23' 19" W	84° 16' 28" W	84° 4' 0" W	84° 44' 52" W
Equipment Manufacturer	Weathertronics	WeatherMeasure	Climatronics	Climet	Climatronics
Wind Speed Sensor:					
Model Number	.2032	W203-HF-3SS	EWS	0603	WS-10
Threshold	.0.5 mph	0.9 mph	0.75 mph	0.6 mph	0.5 mph
Accuracy	.±0.15 mph or 1%	±0.15 mph or 1%	±0.025 mph	±1%	±0.15 mph or 1%
Wind Direction Sensor:					
Model Number	.2020	W104	EWS	0603	WD-10
Threshold	.0.5 mph	0.75 mph	0.75 mph	0.75 mph	0.25 mph
Accuracy	.±1°	±1.8° or 0.5%	±1.5%	±3%	±2.5%
Temperature Sensor:					
Model Number	.4480	Type T Thermocouple	EWS	*	TN-10093
Accuracy	.±0.1° C	±1.5%	±1° F	*	±0.2° C
Output Data:					
Medium	.HP Format Tape	Apple Format Disk	Strip Chart	Strip Chart	DEC Tape
Time Interval	.5 minutes	5 minutes	Continuous	Continuous	1 minute

* This station does not read temperature.

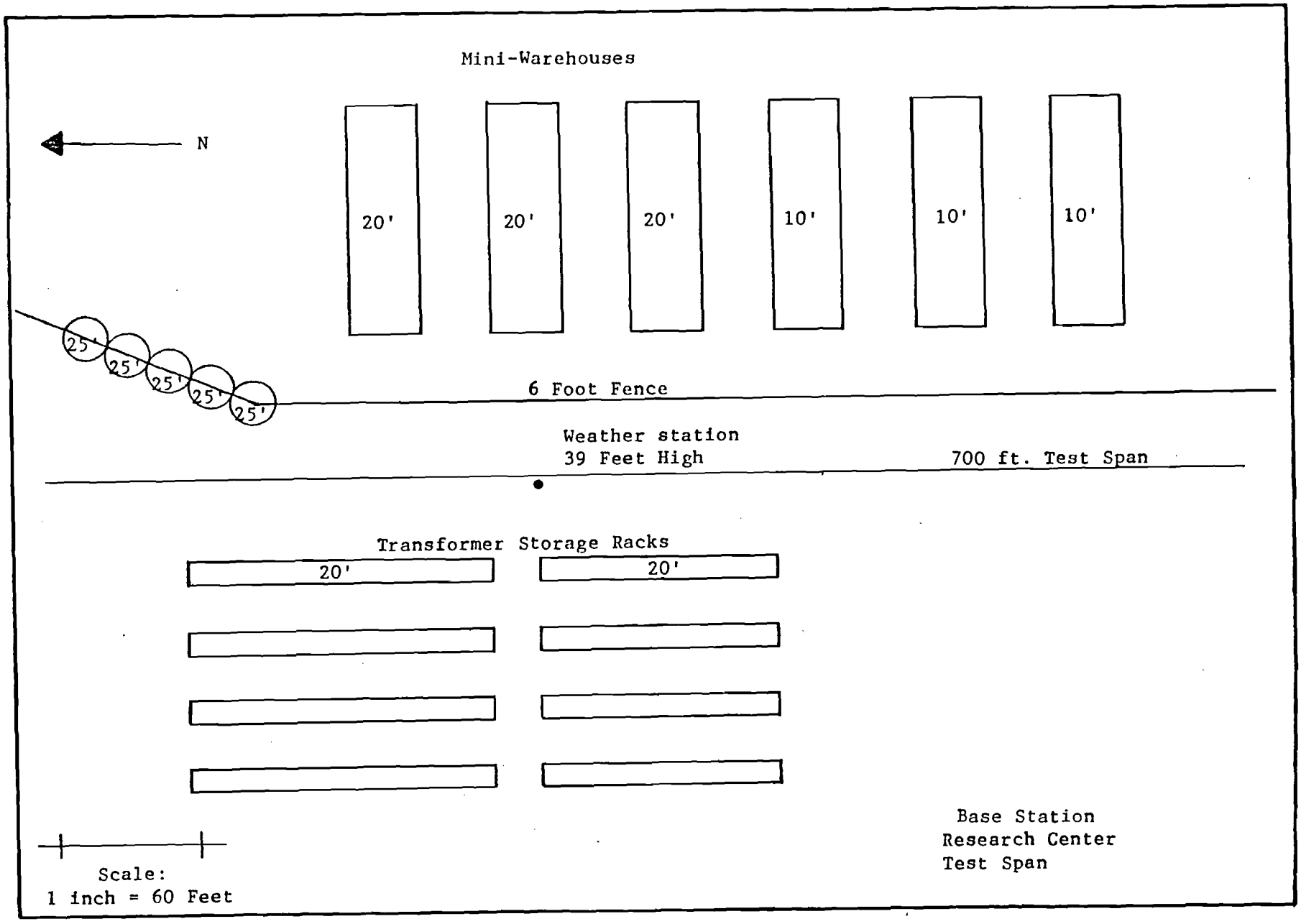

Figure 1. Plan View of Base Station at Forest Park Test Span.

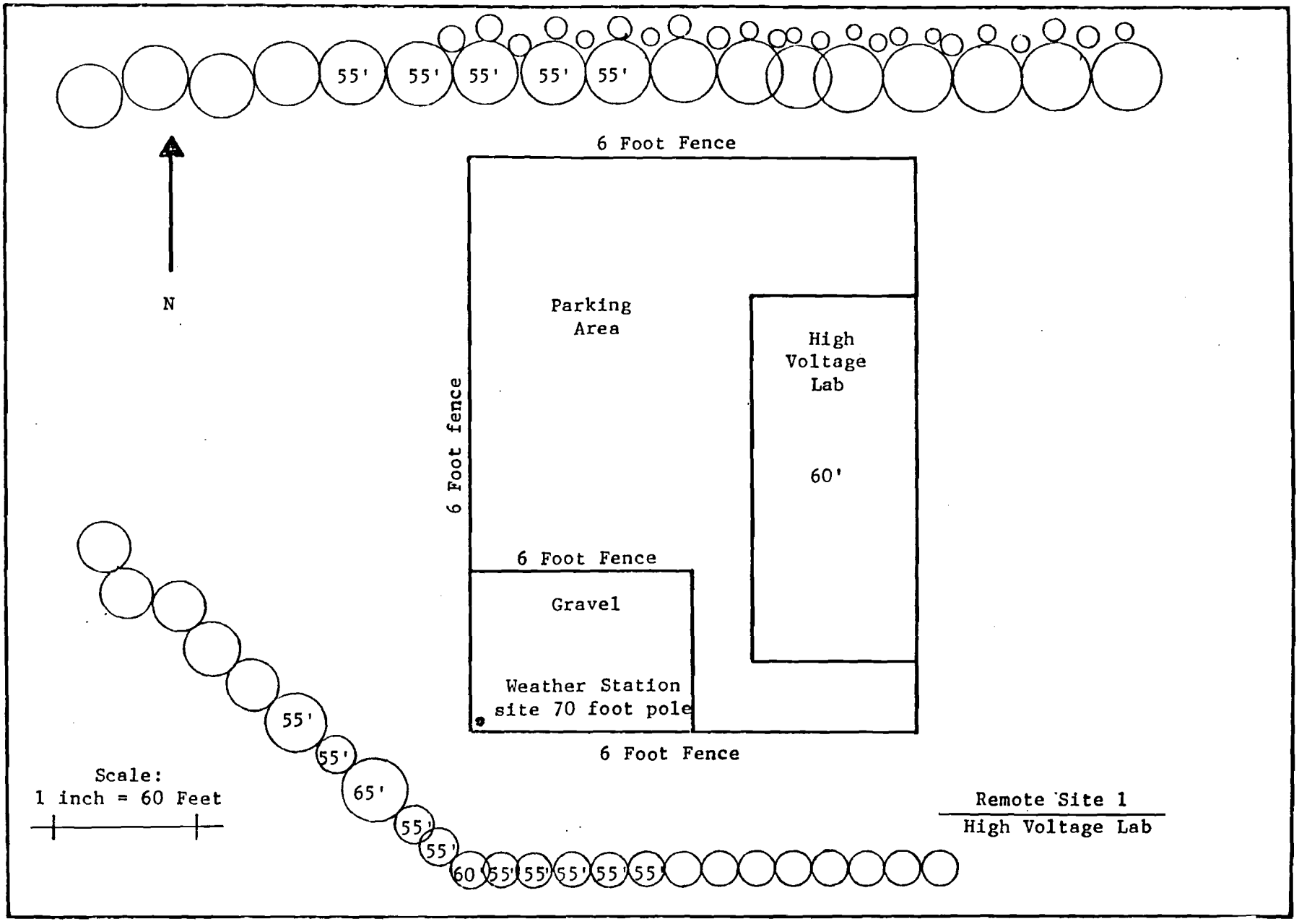

Figure 2. Plan View of Remote Weather Station Number 1.

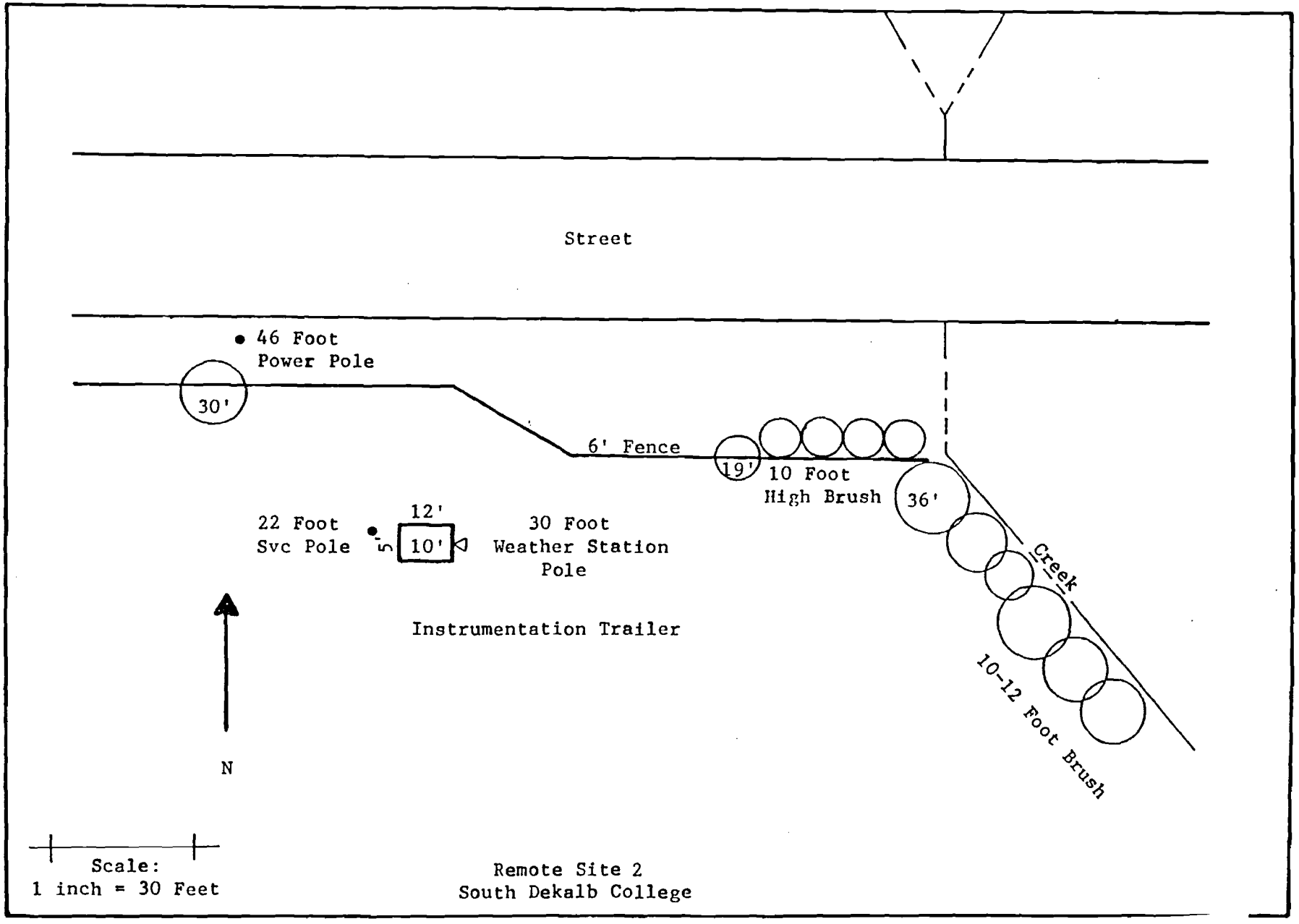

Figure 3. Plan View of Remote Weather Station Number 2.

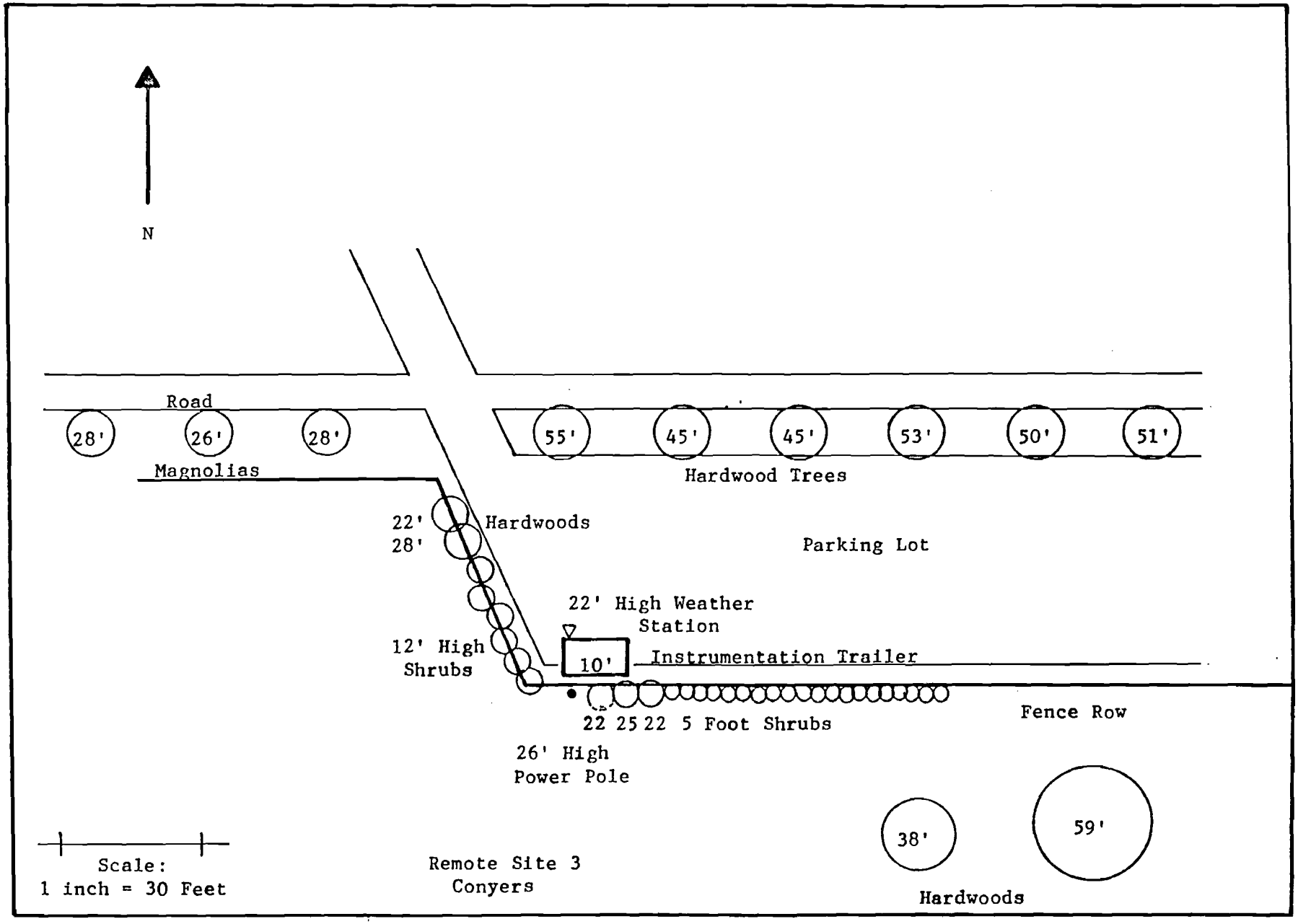

Figure 4. Plan View of Remote Weather Station Number 3.

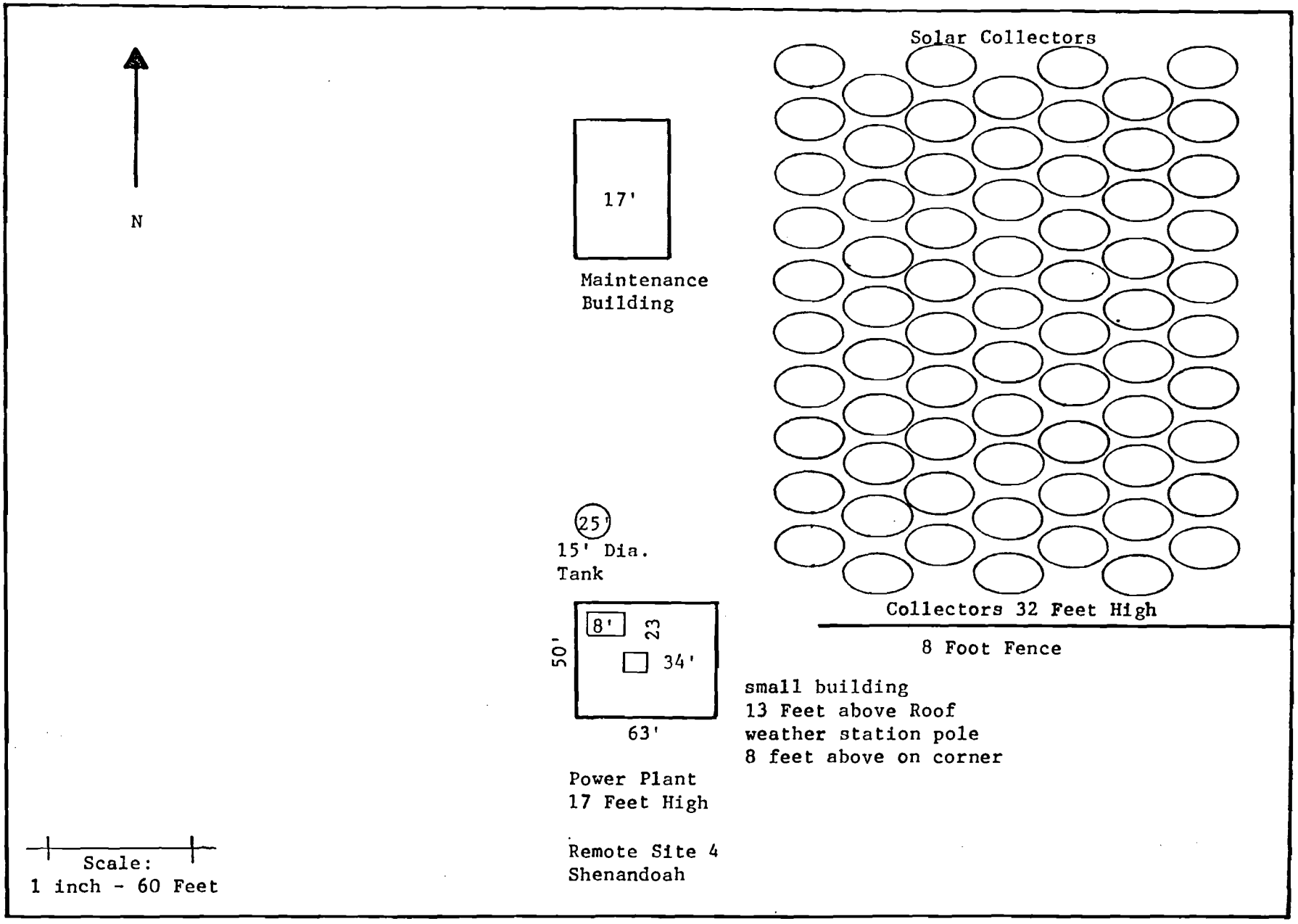

Figure 5. Plan View of Remote Weather Station Number 4.

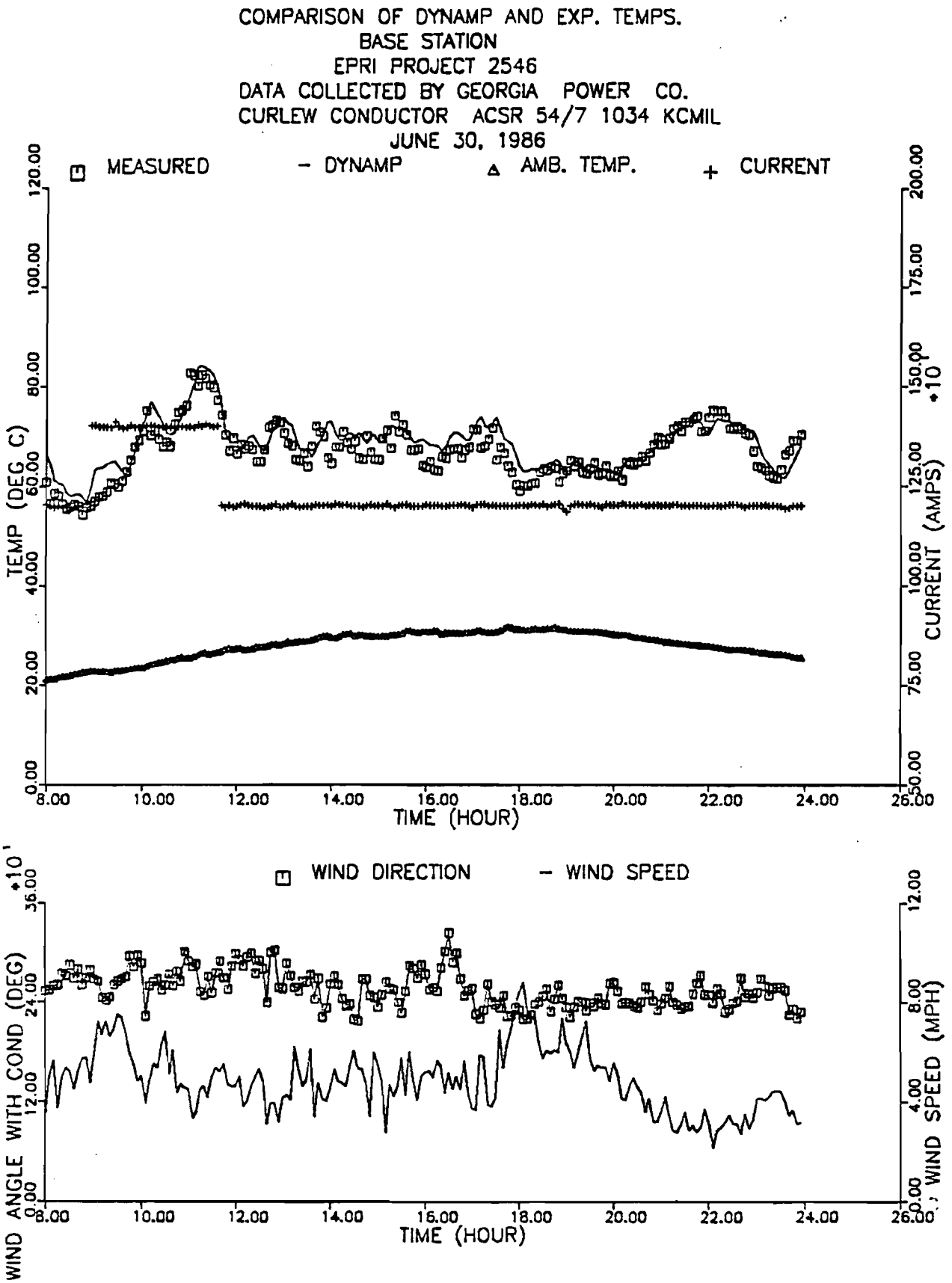

Figure 6. Measured and Predicted Conductor Temperatures and Weather Conditions at Base Station for June 30, 1986.

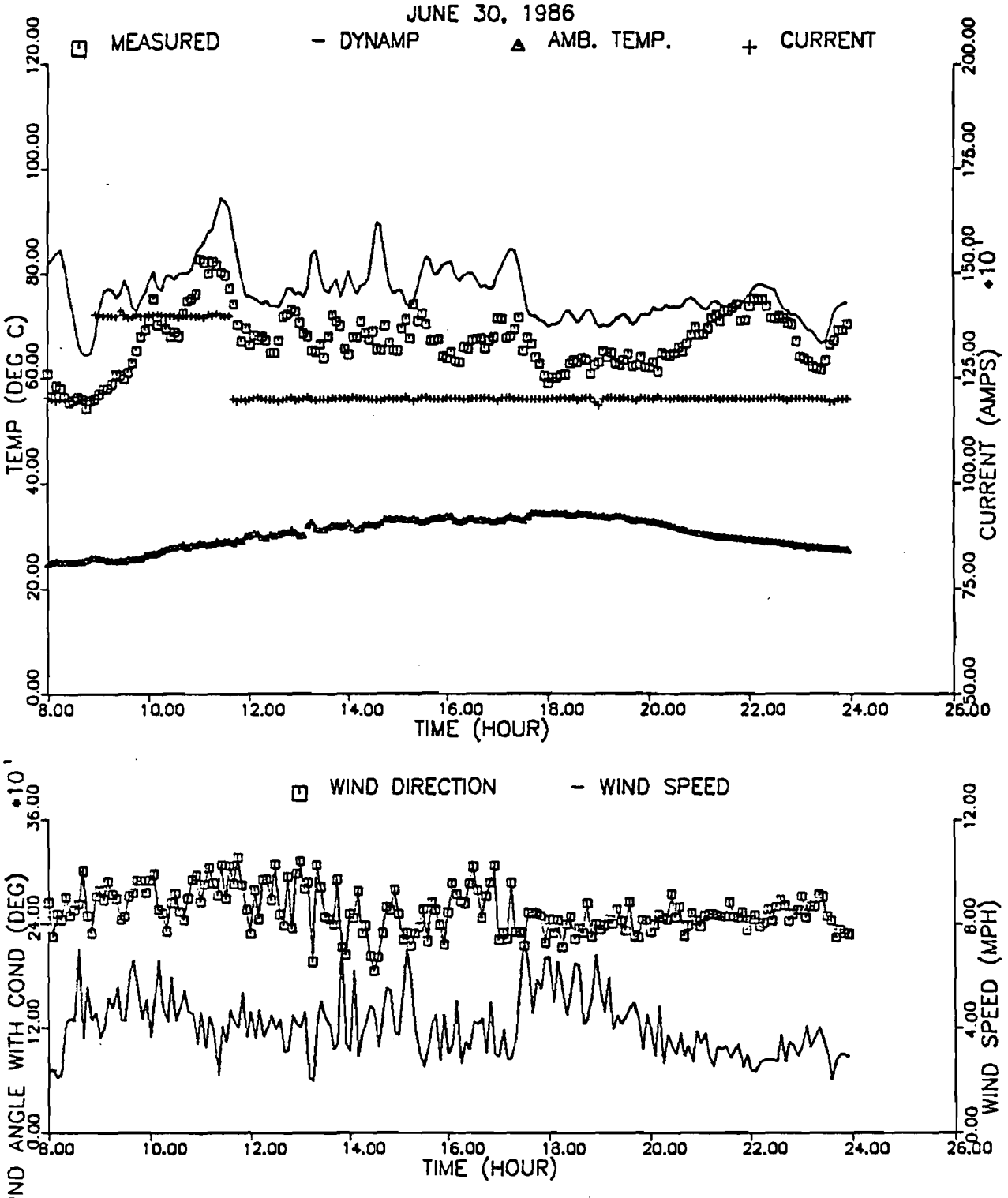

Figure 7. Measured and Predicted Conductor Temperatures and Weather Conditions at Remote Site Number 1 for June 30, 1986.

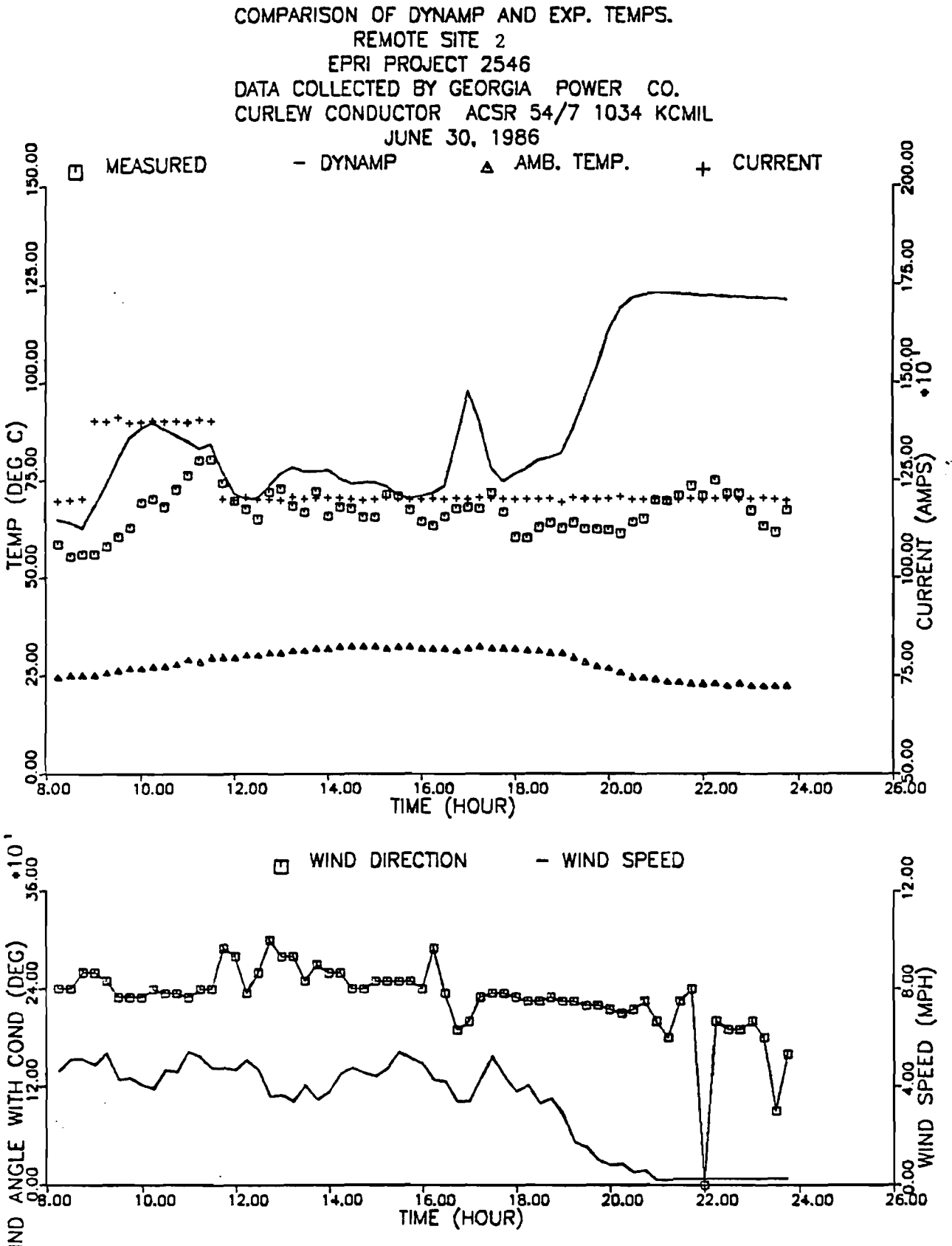

Figure 8. Measured and Predicted Conductor Temperatures and Weather Conditions at Remote Site Number 2 for June 30, 1986.

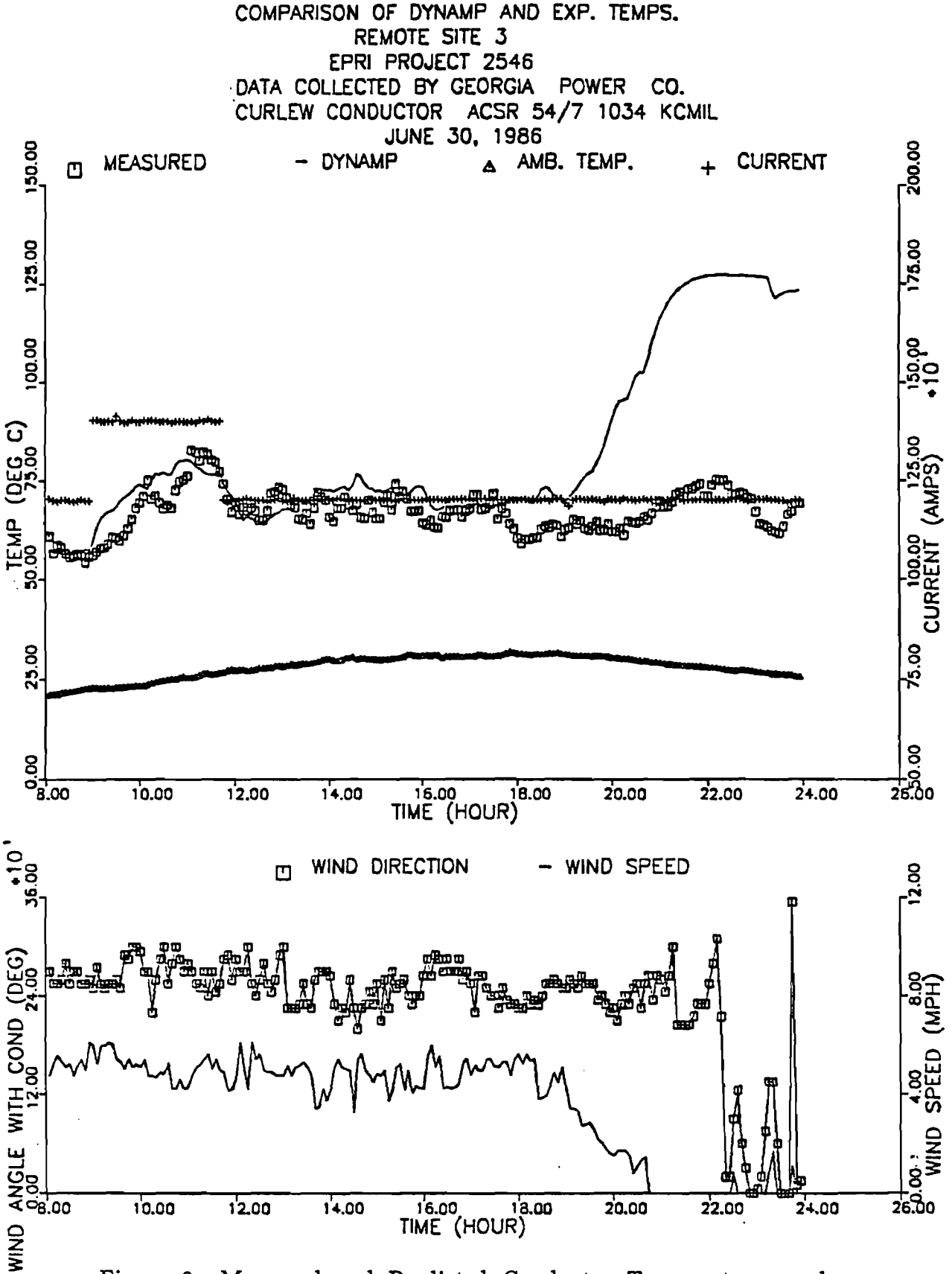

Figure 9. Measured and Predicted Conductor Temperatures and Weather Conditions at Remote Site Number 3 for June 30, 1986.

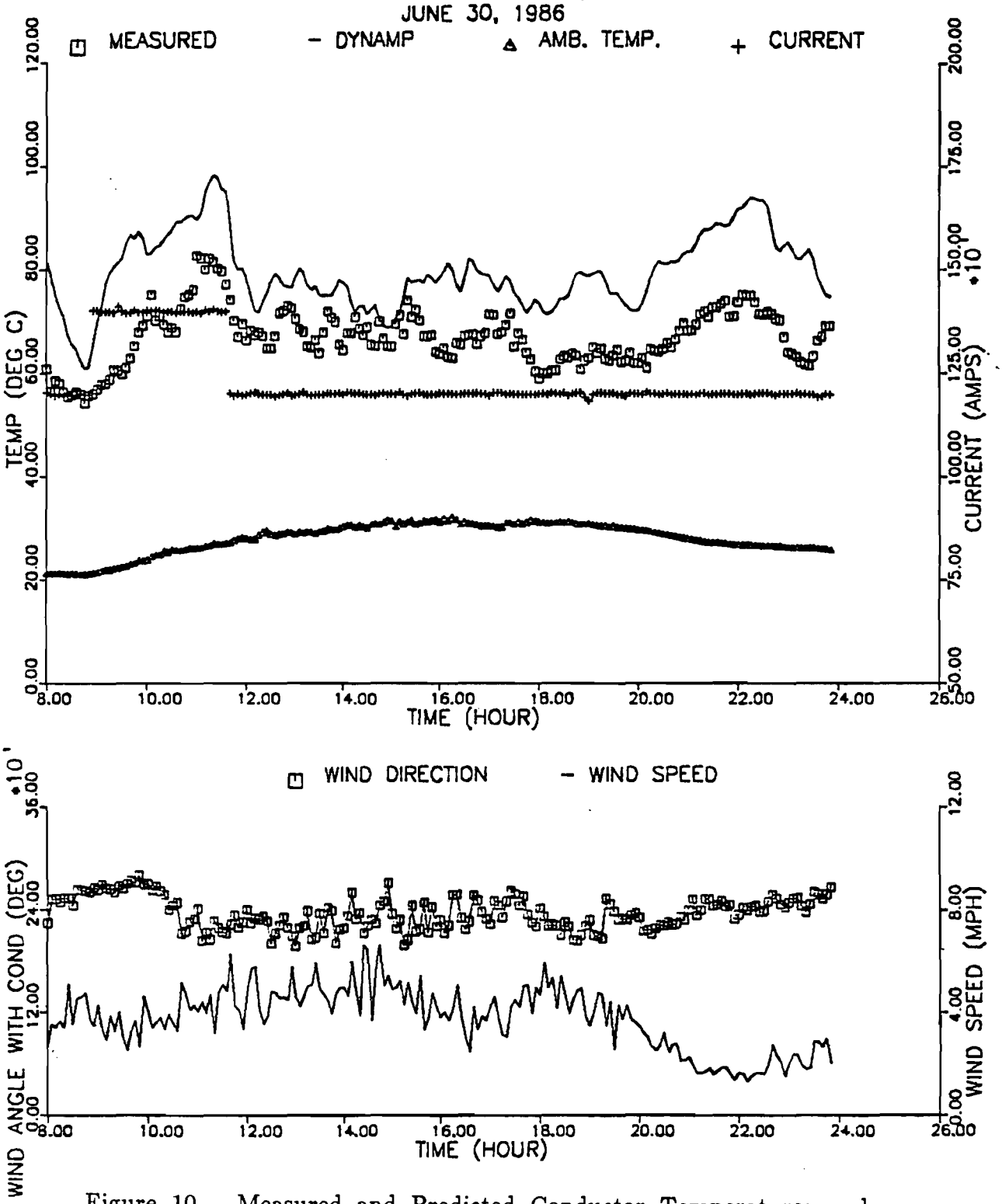

Figure 10. Measured and Predicted Conductor Temperatures and Weather Conditions at Remote Site Number 4 for June 30, 1986.

the test span maintained a good correlation but sites 2, 3 and 4 show large errors. Remote sites 2 and 3 show errors in prediction of 50°C when the wind speed as measured at these sites dropped to zero. At low wind speeds, the two state EPA sites (sites 2 and 3) consistently showed poor correlations.

The data collected throughout the Idaho Power Project is being statistically analyzed to evaluate the applicability of this information to critical span analysis.

C. KEURP Project

The Kansas Electric Utility Research Program (KEURP) entered into a co-funding agreement with EPRI on work relating to the EPRI research project 2546. KEURP provided funding to evaluate dynamic line rating systems using data collected at field sites for four conductor sizes. Both the weather data based DYNAMP program and the line monitor were evaluated. The operation of DYNAMP for weather conditions that exist in Kansas will give an idea of the program accuracy for weather that differs significantly from that in Georgia. Also the program carried out in Kansas will give added operating experience in use of line monitors.

The weather conditions and topography of each service area greatly affect the current carrying capacity of an overhead conductor. The strong prevailing winds and flat terrain in Kansas contrasts drastically from the Georgia Piedmont which typically has light to moderate wind speeds and a hilly terrain. The results obtained in Kansas coupled with the data generated in Georgia will hopefully show the applicability of

dynamic line rating system for two greatly different geographical locations.

Between July 23 and October 7, 1986, data was collected on four different conductor sizes at two different locations as shown in Table 3.

Table 3. Kansas Field Sites

Conductor Size	Conductor Type	Generating Plant
795 ACSR	Drake	Gordon Evans
666 ACSR	Flamingo	Gordon Evans
954 ACSR	Rail	Weaver
477 ACSR	Hawk	Weaver

The initial work was performed on a 795 Drake conductor adjacent to the Gordon Evans Generating Plant Substation outside Wichita. An EPRI weather station was installed within 25 feet of the transmission line at conductor height. Problems were encountered with the weather station including induced voltage from the transmission line and lightning damage.

This station was ultimately replaced by a weather station provided by Wichita State University. Initial software problems in data collection were also resolved. Data were obtained from this site over a three day period. The equipment was then relocated and data collected over three day periods at each of the next three sites.

The transmission lines operated by KG&E are not heavily loaded at the present time. Therefore conductor temperatures below 50°C were commonly encountered even though the ambient temperature was frequently in excess of 33°C during the test period. Switching was performed on the system to obtain higher currents and correspondingly higher temperatures.

After the test program at KG&E was completed, the line monitor was returned to Georgia Power Company October 7, 1986. The monitor was installed on the Forest Park test span to determine if any drift in the readings had occurred. Monitor temperature data was collected over a two-week period and the temperatures obtained were compared to surface conductor temperatures measured with thermocouples (Figure 11). The data sets were randomly selected without regard to wind speed or direction. Although differences of 10°C to 15°C did exist, the least square curve fit shows that on average the monitor and measured temperatures compared well. A comparison of the calibration results obtained before and after use at KG&E indicates that no significant drift in the readings of the device occurred.

The effects of wind direction on the accuracy of the monitor were then evaluated. The test span is oriented in a north/south direction and the monitor was installed with the jaw opening facing to the east. Figures 12-15 indicate that errors do exist which are a function of wind direction. The monitor reads high when the wind is from the west because the jaws are sheltered from the wind by the monitor housing. The average monitor temperature is low when the wind blows from any of the other three quadrants.

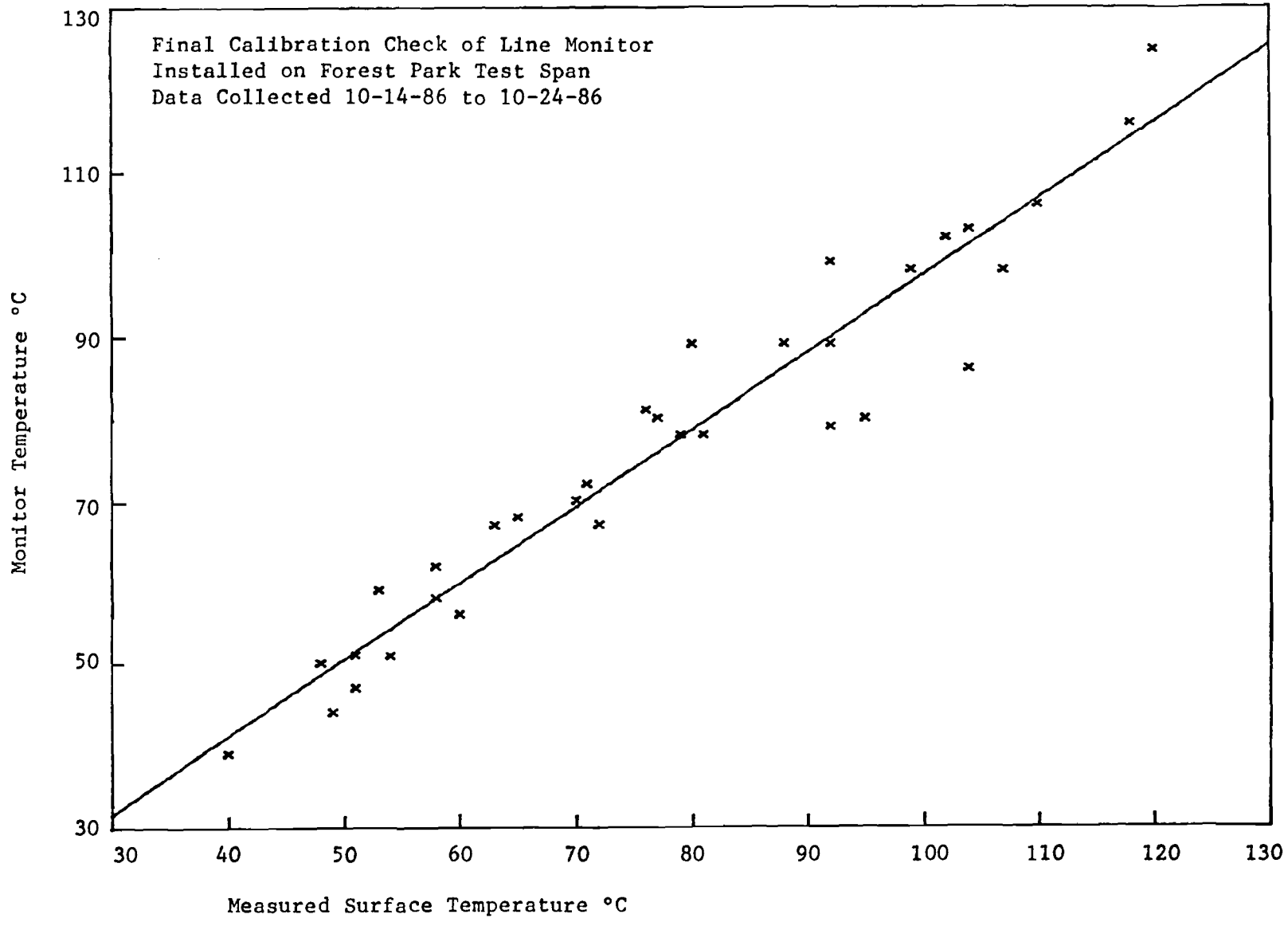

Figure 11. Calibration of Line Monitor after Use in KG&E Project.

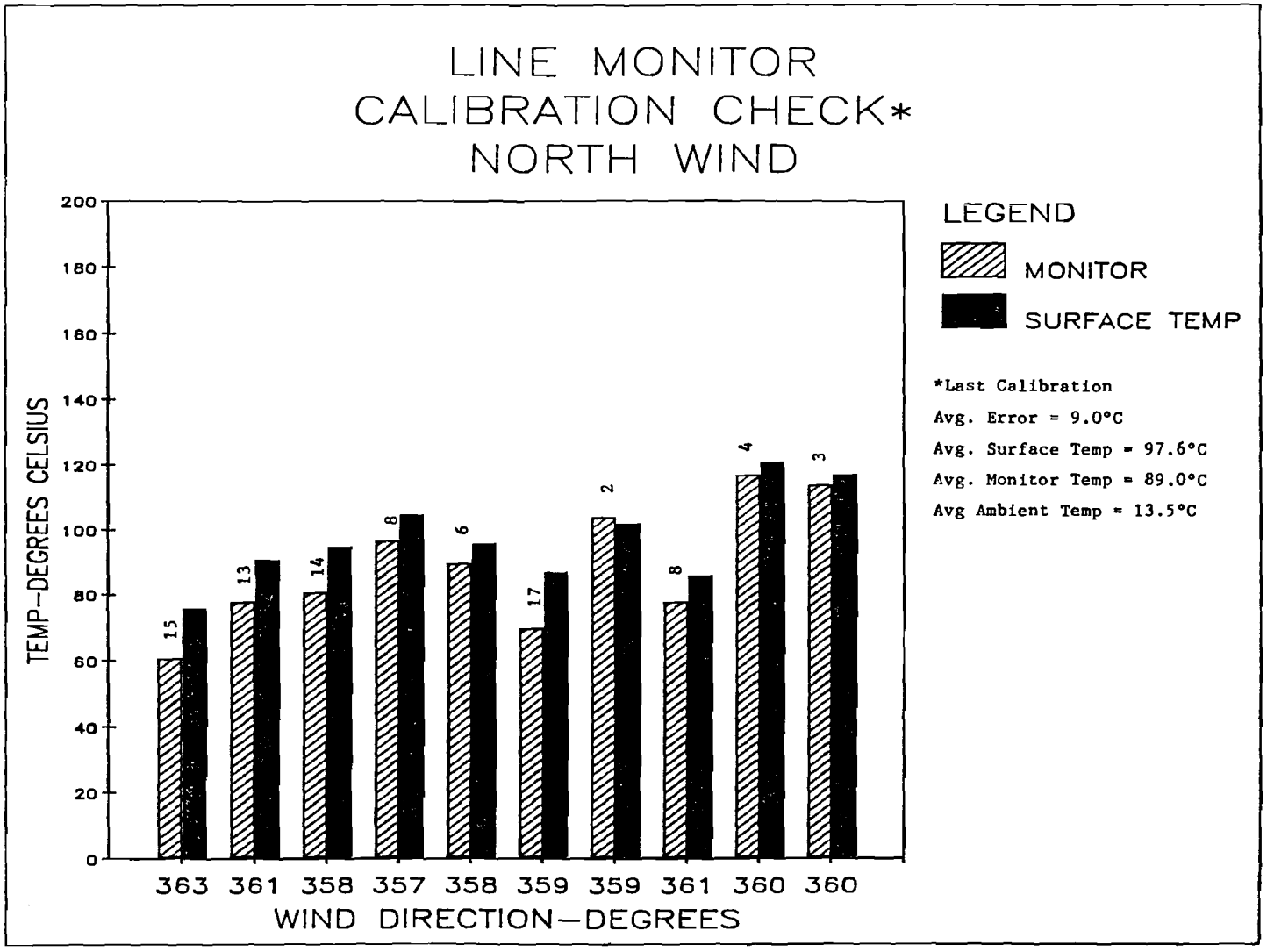

Figure 12. Errors in Line Monitor Temperature when Wind is from the North.

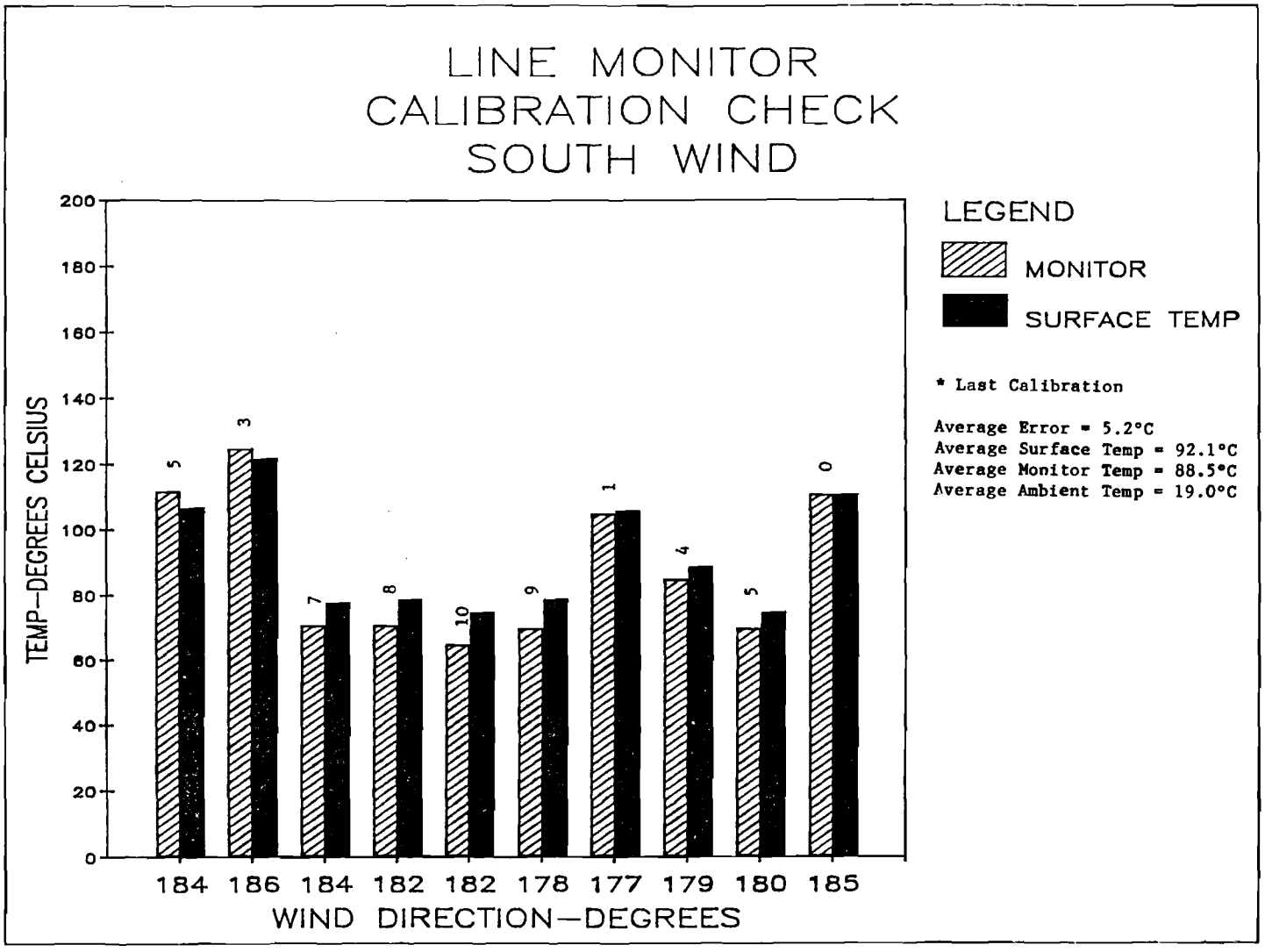

Figure 13. Errors in Line Monitor Temperature when Wind is from the South.

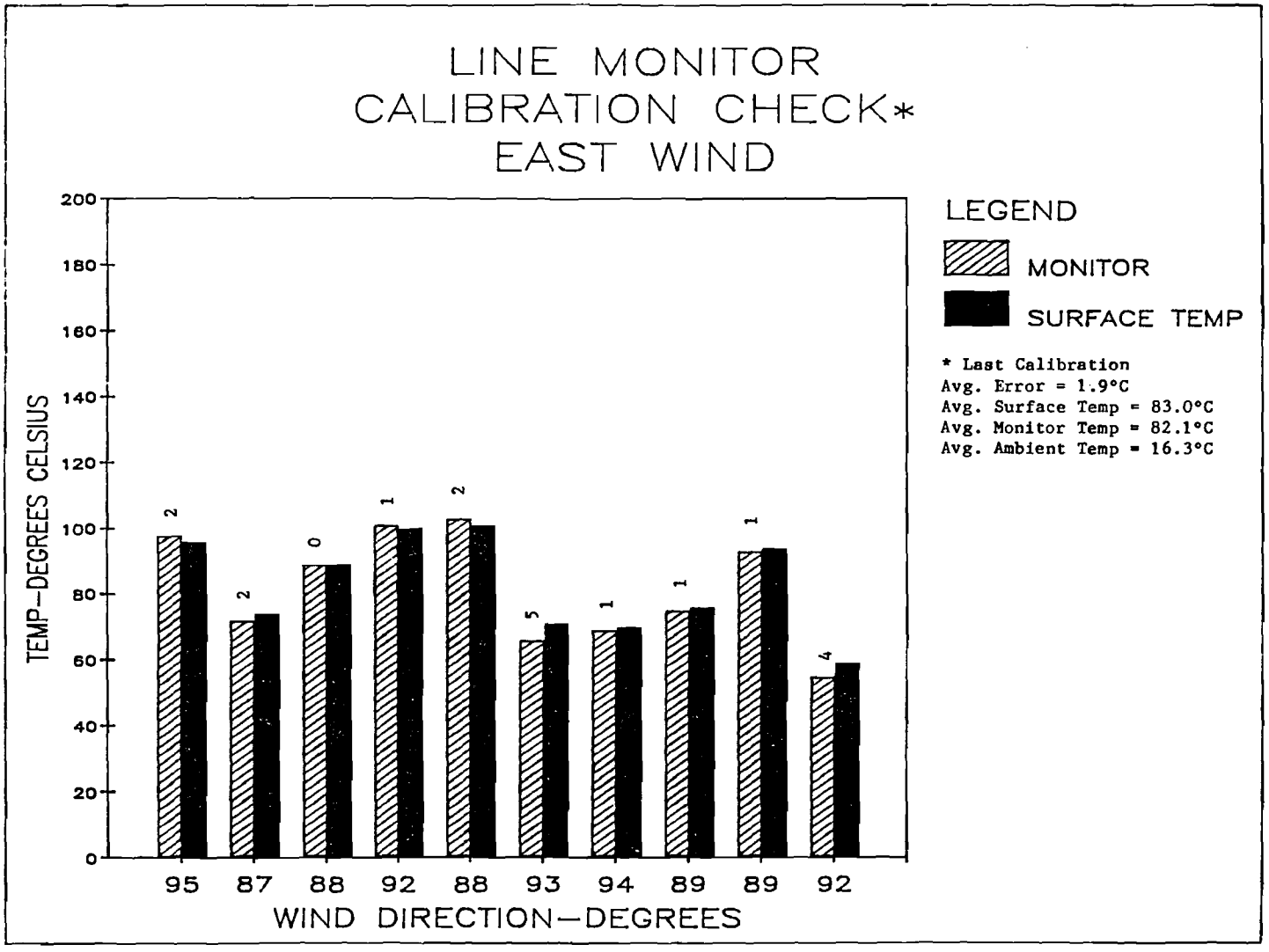

Figure 14. Errors in Line Monitor Temperature when Wind is from the East.

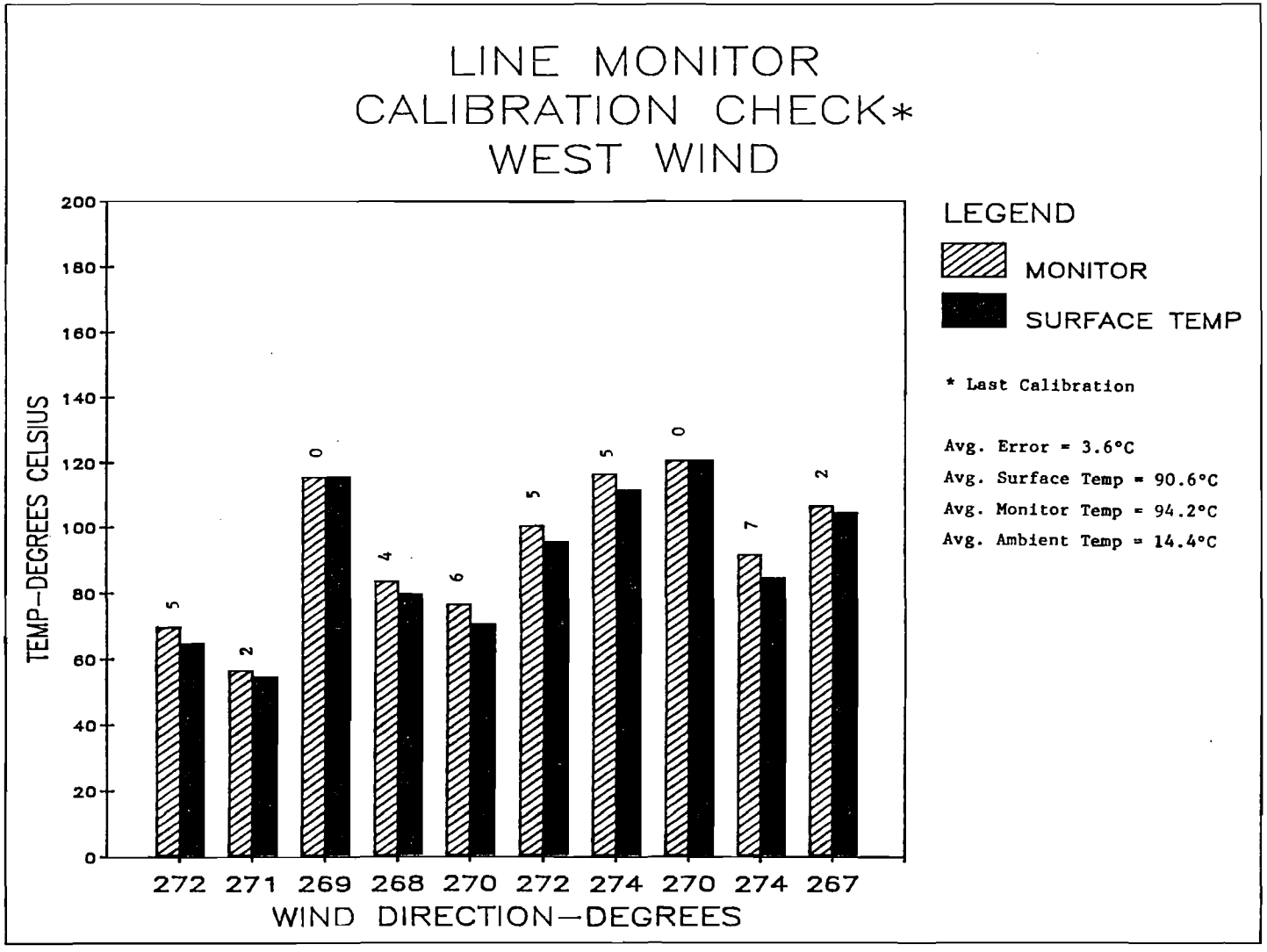

Figure 15. Errors in Line Monitor Temperature when Wind is from the West.

II. THEORETICAL PHASE

A. Additional Developments with DYNAMP

1. Version 1.2

The computer program has remained practically unchanged since the last meeting in Boise Idaho. No significant programming errors have been uncovered and the only major changes to the code have been to improve program efficiency or decrease run time. The changes in Version 1.2 are listed below.

a. The expression for the free convection Nusselt number calculated in the subroutine HTC (Heat Transfer Coefficient) was modified to account for the angle that the conductor makes relative to the horizon. The previous expression assumed that the conductor was horizontal when calculating the free convection Nusselt number. The new expression decreases the Nusselt number as the conductor is inclined to the horizon. The result of this change will be to increase the conductor temperature at low wind velocities when the conductor is not horizontal.

b. The expression that calculates the angle between the conductor axis and the wind velocity has been modified to eliminate improper round-off errors. In rare instances certain wind directions cause the program to attempt to calculate an angle whose sine was greater than one. Code was inserted into subroutine HTC to prevent this occurrence.

c. In two places in the program negative numbers were raised to the power 2.0. Fortran does not permit a negative number to be raised to floating point numbers. It is, however, permissible to square a negative number by raising it to the integer 2. The decimal point was removed from two exponents, one in the subroutine HTC and the other in the radiation subroutine called HTC.

d. In rare instances an arithmetic overflow occurred in the subroutine that calculates the incident solar load on the conductor. For certain dates and times at certain latitudes and longitudes, the program attempts to calculate an infinite value for the thickness of the atmospheric layer surrounding the earth that the sun must penetrate. Several statements were inserted in the code to prevent that behavior and calculate the limiting value for the air mass rather than attempting to use the statement that causes the overflow condition.

e. The number of significant figures accepted in the input file for the variables of wind velocity, AC resistance of the conductor, time interval between weather data and time interval between output information were all increased.

f. The dimension of the variables called NAME and ANAME were increased from 15 to 20. This change was

necessary so that the IUF portion of the program was able to recognize the bird name for ACSR conductors.

g. The array size of two variables in the subroutine QRAD were reduced from 62 to 14.

h. The common blocks in all subroutines were checked and reduced by placing many of the variables previously that were in common blocks into the argument lists.

i. Several repetitive calculations have been eliminated in order to decrease the run time of the program.

Version 1.2 first became available in August 1986. The program along with a revised users manual has been mailed to six users. No comments have been received regarding the operation of Version 1.2 of DYNAMP.

All additional weather data collected since the June 1986 meeting have been run through DYNAMP. No unusual conditions have been observed and DYNAMP continues to predict the measured line temperature to within approximately $\pm$ 10°C for temperatures up to 125°C. A statistical analysis of all data collected to date and a comparison of DYNAMP's accuracy is given in the next section of this report.

Several typical curves of measured and predicted conductor temperatures for some of the more recent data are shown in Figures 16 through 19.

Figure 16 for data collected on October 15, 1986 shows typical results similar to those obtained over the past year. Differences between DYNAMP's predicted temperatures and the measured line

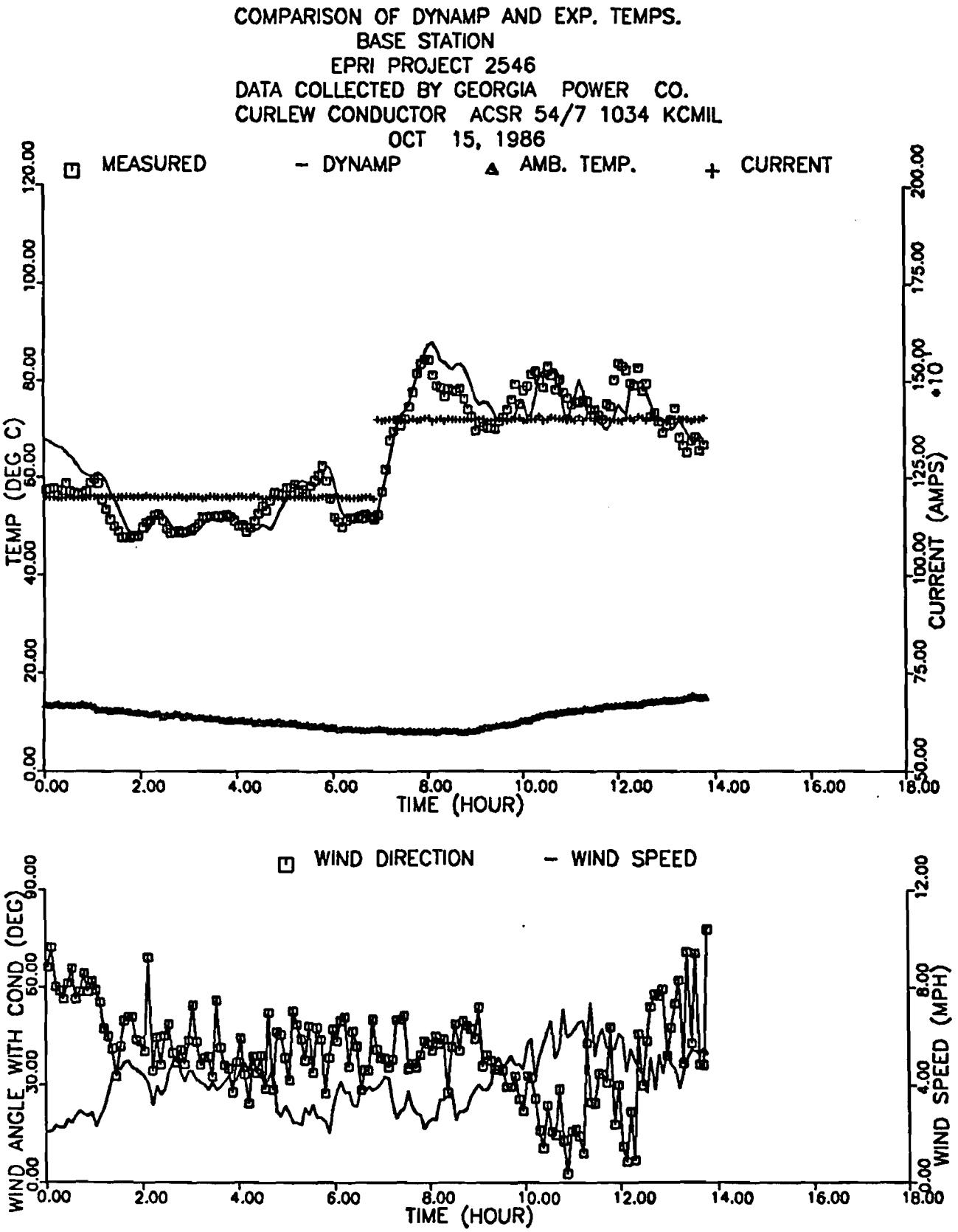

Figure 16. Measured and Predicted Conductor Temperatures for October 15, 1986.

temperatures average less than about 5°C over the 14 hours that data were collected. The data for October 20th shown in Figure 17 was collected during a period of much higher current and during that period the conductor temperature exceeded 125°C. Even at these high temperatures the trends predicted by DYNAMP remained excellent.

The data in Figures 18 and 19 give an indication of the relatively large errors that can result when the wind velocity decrease to zero and the wind direction is down the axis of the conductor. Figure 18 for conditions on October 21 shows expected accuracy except for two brief periods. Around midnight (between 0:00 and 1:00 am) the wind was very calm and the program predicted temperatures that were at times both high and low of the measured values. As the wind velocity began to increase after 1:00 am, the usual accuracy of the program returned and it remained excellent with the exception of one brief period at approximately noon. At that time the wind was blowing down the axis of the conductor (wind angle = 0) and the program briefly predicted a temperature that was about 30°C higher than the measured temperature. Once the wind changed direction and the wind angle increased, the program accuracy returned.

The data in Figure 19 for October 22, 1986 shows more sustained errors as a result of much longer periods when the weather station was indicating no wind was present at the conductor location. The weather station reported practically no wind from midnight until slightly after 6:00 am. Program errors during that same period averaged about 20°C.

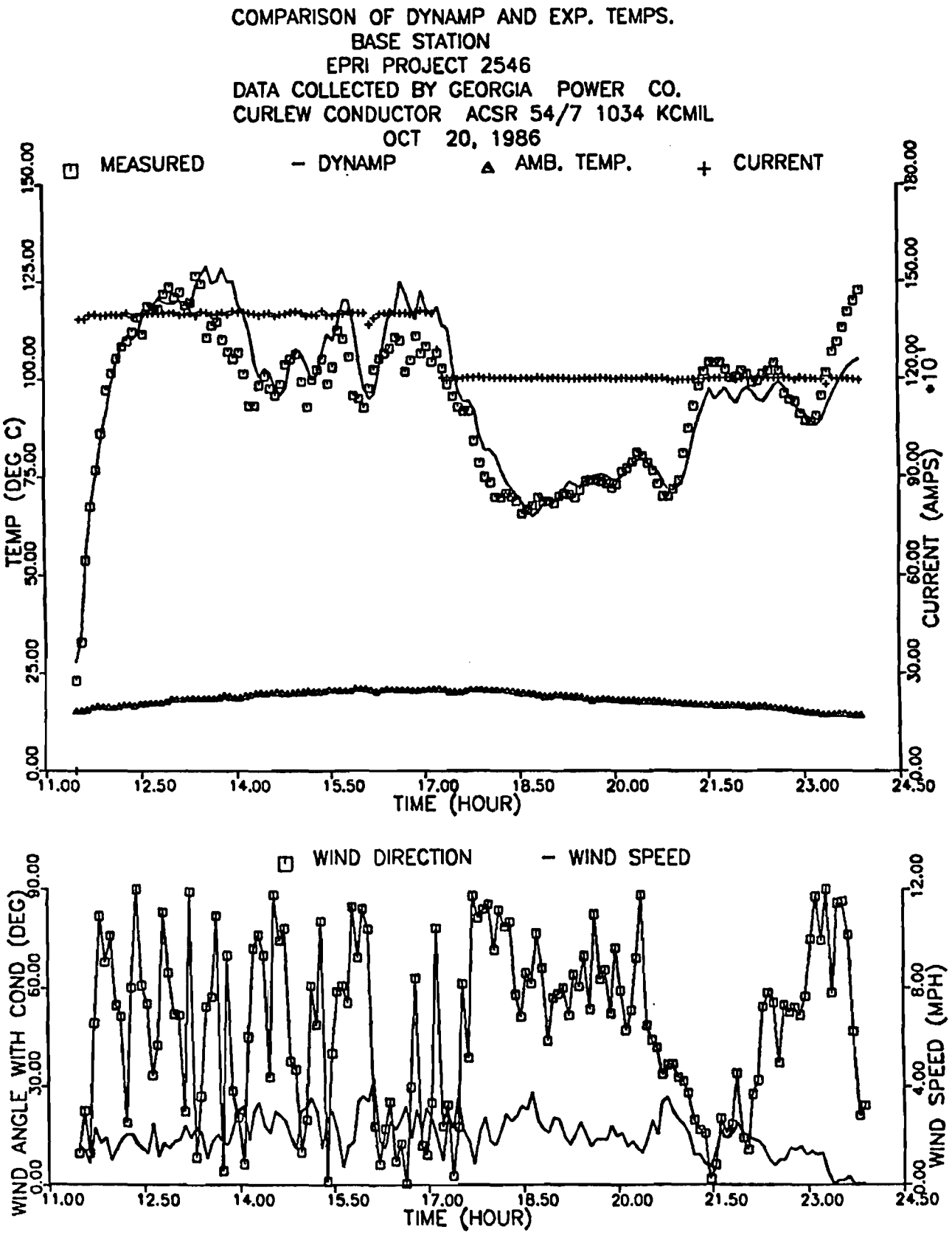

Figure 17. Measured and Predicted Conductor Temperatures for October 20, 1986.

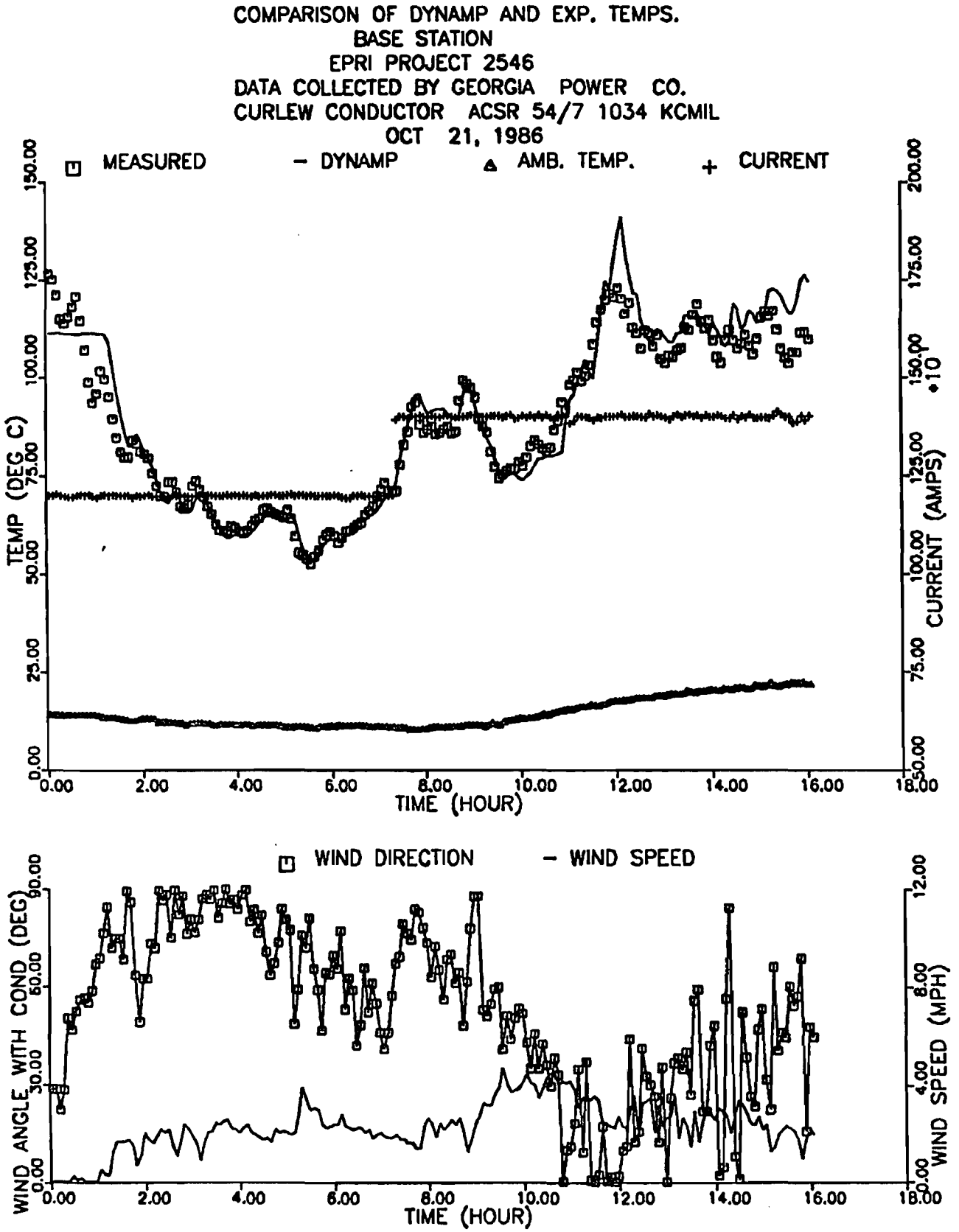

Figure 18. Measured and Predicted Conductor Temperatures for October 21, 1986.

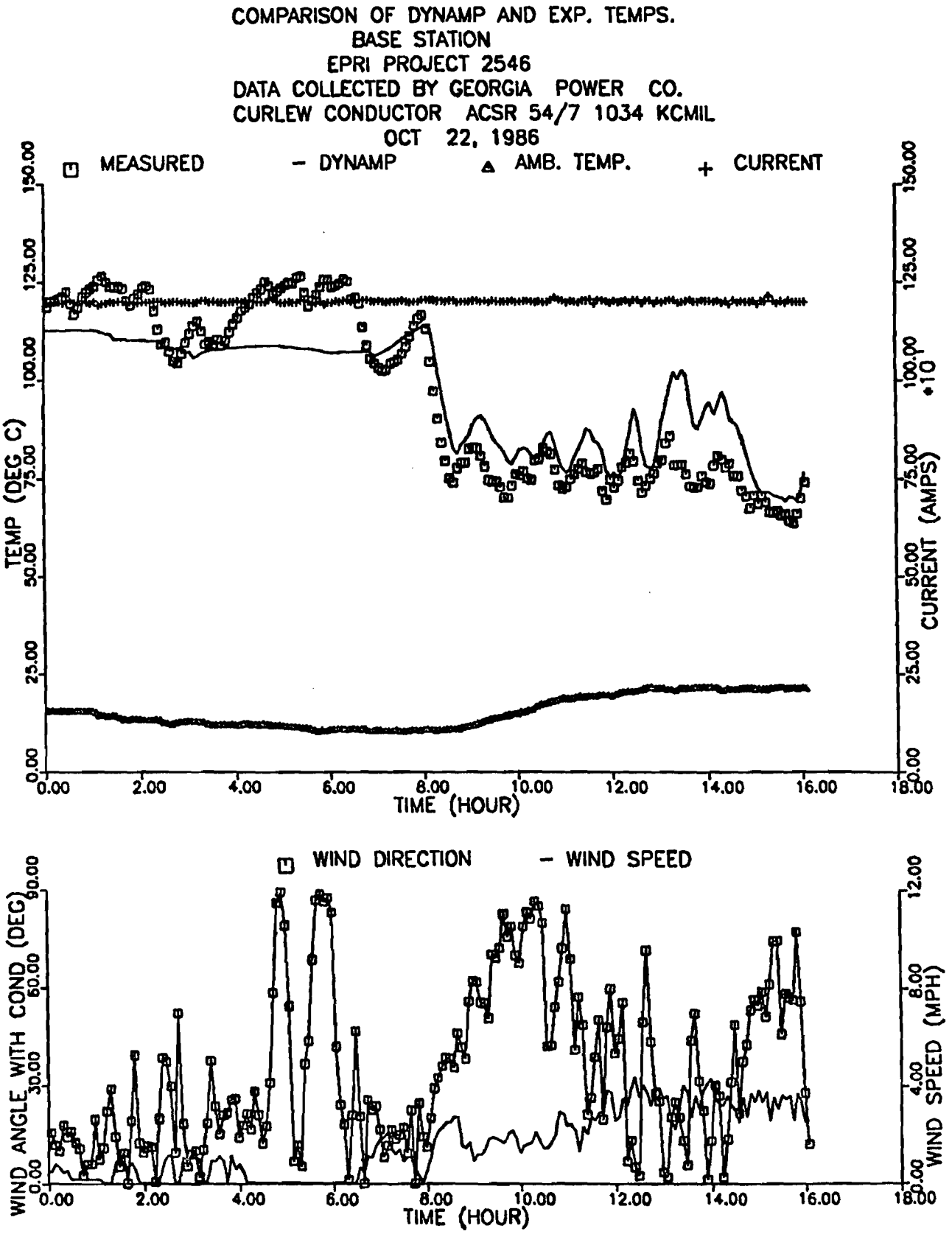

Figure 19. Measured and Predicted Conductor Temperatures for October 22, 1986.

Since the test span at Forest Park has been partially dismantled, no more experimental data can be collected and the program to check DYNAMP's accuracy has been completed.

2. Interactive Version of DYNAMP

A copy of Version 1.2 was forwarded to Power Computing Company in September 1986. PCC revised the program by inserting an Interactive, User Facility (IUF) front-end program. The IUF version of DYNAMP has been check at both EPRI and Georgia Tech and several errors have been corrected. Other suggestions have been made to improve program operation. A preliminary version of the IUF program is now available and will be demonstrated at the end of the meeting.

B. Statistical Analysis of DYNAMP's Predictions

During the two year period in which the test span was operated, the Curlew conductor was in place for about 15 months. During that time over 26,400 data points of weather conditions, current and conductor temperature were collected and recorded on diskette. This number represents nearly 92 days of continual operation. All of these data points have been analyzed with DYNAMP and a statistical analysis of the program accuracy has been performed.

The result of the statistical analysis is shown in Tables 4 through 6. These tables include a total population of 24,700 data points out of the 26,400 points collected. The difference in these two numbers represents the data collected during periods of rain and the first few minutes at the beginning of each new collection period. At both of these times DYNAMP is known to be inaccurate, because it does not

account for the evaporative cooling that occurs during rainfall and it is not able to predict the real-time temperature when it is given only a single weather data point at the beginning of a run. Therefore, these points were removed from the statistical package so that a true picture of the program accuracy would emerge.

The data in Table 4 shows the errors that resulted with DYNAMP for the total population of 24,700 data points collected over the 15 month period the test span was in operation with the Curlew conductor. The errors which appear in the table are defined as the difference between DYNAMP's predicted temperature and the average reading of the 16 thermocouples that were mounted on the line. DYNAMP's predicted temperature was within $\pm$ 0.5°C for 2817 of the data points or 11.4% of the time. Over half of the data points collected resulted in an error of $\pm$ 2°C and greater than 90% of the data points were within $\pm$ 8°C of the correct temperature.

Over 61% of the data resulted in DYNAMP predicting a temperature greater than the measured conductor temperature. Only 27% of the predicted temperatures were less than the measured value. This behavior of over-predicting the conductor temperature was intentional, because the program was designed to be on the conservative side.

The data in Tables 5 and 6 contain the same data as shown in Table 4 except that Table 5 contains only those points for which DYNAMP over-predicted the temperature and Table 6 shows only those cases where DYNAMP calculates a temperature lower than the measured value. These values show that more accurate predictions occur at higher wind

BASE STATION

TEMPERATURE RANK PERCENTAGES

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
0	2817	11.4	11.4	53.7	21.3	5.7	2.6	1.5	0.00	98.5
1	5423	22.0	33.4	54.5	21.2	5.7	2.7	2.2	0.00	97.8
2	4277	17.3	50.7	53.1	21.4	6.0	3.1	2.8	0.00	97.2
3	3123	12.6	63.3	52.1	22.6	6.0	3.4	4.1	0.00	95.9
4	2238	9.1	72.4	50.7	22.9	5.7	3.4	5.1	0.00	94.9
5	1628	6.6	79.0	48.8	23.3	5.4	3.2	5.3	0.00	94.7
6	1210	4.9	83.9	45.9	23.8	5.2	3.2	8.3	0.00	91.7
7	935	3.8	87.7	44.7	24.7	4.9	3.1	10.1	0.00	89.9
8	686	2.8	90.4	40.1	25.3	4.8	3.2	13.6	0.00	86.4
9	474	1.9	92.4	37.9	24.2	4.4	2.7	13.9	0.00	86.1
10	368	1.5	93.8	35.3	24.6	4.7	3.1	15.5	0.00	84.5
11	281	1.1	95.0	35.6	25.6	4.7	2.9	13.2	0.00	86.8
12	215	0.9	95.9	34.0	24.6	4.5	3.1	19.1	0.00	80.9
13	193	0.8	96.6	35.7	24.8	4.1	2.9	20.2	0.00	79.8
14	146	0.6	97.2	38.0	27.5	4.6	3.2	18.5	0.00	81.5
15	109	0.4	97.7	32.1	25.2	4.7	3.5	22.0	0.00	78.0
16	87	0.4	98.0	34.0	25.0	4.4	3.2	19.5	0.00	80.5
17	76	0.3	98.3	29.6	24.8	4.6	3.2	27.6	0.00	72.4
18	66	0.3	98.6	31.0	27.5	4.0	2.8	22.7	0.00	77.3
19	47	0.2	98.8	28.7	28.2	5.1	3.1	19.1	0.00	80.9
20	49	0.2	99.0	31.4	26.8	5.2	3.5	10.2	0.00	89.8
21	46	0.2	99.2	32.7	26.5	5.6	3.5	10.9	0.00	89.1
22	28	0.1	99.3	30.4	27.7	5.4	3.0	3.6	0.00	96.4
23	23	0.1	99.4	28.1	23.9	4.8	3.6	8.7	0.00	91.3
24	27	0.1	99.5	24.5	22.4	5.7	3.6	11.1	0.00	88.9
25	15	0.1	99.5	42.1	26.4	4.3	2.3	20.0	0.00	80.0
26	8	0.0	99.6	24.4	26.3	5.0	4.5	25.0	0.00	75.0
27	10	0.0	99.6	33.5	30.2	3.7	3.0	40.0	0.00	60.0
28	8	0.0	99.6	45.0	25.9	4.1	2.9	12.5	0.00	87.5
29	7	0.0	99.7	31.3	31.5	4.4	2.1	14.3	0.00	85.7
30	5	0.0	99.7	16.8	18.1	5.6	1.3	0.0	0.00	100.0
31	10	0.0	99.7	26.4	26.3	5.1	1.6	10.0	0.00	90.0
32	9	0.0	99.8	17.5	26.7	5.9	2.1	33.3	0.00	66.7
33	12	0.0	99.8	35.1	29.8	4.7	2.0	8.3	0.00	91.7
34	7	0.0	99.9	22.4	20.5	4.8	1.6	28.6	0.00	71.4
35	3	0.0	99.9	32.3	36.1	6.3	1.7	0.0	0.00	100.0
36	6	0.0	99.9	14.5	14.4	4.2	1.5	50.0	0.00	50.0
37	2	0.0	99.9	38.0	1.4	5.7	3.1	0.0	0.00	100.0
38	4	0.0	99.9	26.2	4.6	4.0	1.7	0.0	0.00	100.0
39	6	0.0	99.9	24.0	11.0	4.3	1.4	16.7	0.00	83.3
41	1	0.0	99.9	13.0	0.0	5.3	0.0	0.0	0.00	100.0
42	1	0.0	99.9	19.0	0.0	2.3	0.0	0.0	0.00	100.0
43	1	0.0	99.9	69.1	0.0	2.8	0.0	0.0	0.00	100.0
44	1	0.0	100.0	1.0	0.0	5.5	0.0	0.0	0.00	100.0
50	12	0.0	100.0	36.1	27.5	4.3	3.2	25.0	0.00	75.0

Table 4. Statistical Analysis of DYNAMP's Predicted Temperatures for a Total of 24,700 Data Points.

DYNAMP PREDICTS EXACTLY AS MEASURED FOR 11.4 %

DYNAMP PREDICTS HIGHER THAN MEASURED FOR 61.5 %

DYNAMP PREDICTS LOWER THAN MEASURED FOR 27.1 %

MEAN TEMPERATURE ERROR IN DEGREES C (DYNAMP > MEASURED) : 4.5 +/- 4.5

MEAN TEMPERATURE ERROR IN DEGREES C (DYNAMP < MEASURED) : 3.6 +/- 3.7

NUMBER OF DATA POINTS (DYNAMP > MEASURED) : 15191

NUMBER OF DATA POINTS (DYNAMP < MEASURED) : 6692

NUMBER OF DATA POINTS (DYNAMP = MEASURED) : 2817

TOTAL DATA POINTS ANALYZED : 24700

Table 4. (Continued)

BASE STATION

T E M P E R A T U R E R A N K P E R C E N T A G E S

DYNAMP PREDICTS HIGHER THAN MEASURED

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
1	3314	13.4	34.0	55.7	20.7	6.1	2.8	1.7	0.00	98.3
2	2856	11.6	49.9	54.6	20.9	6.8	3.2	1.9	0.00	98.1
3	2205	8.9	62.2	54.1	21.8	6.9	3.4	2.4	0.00	97.6
4	1643	6.7	71.3	52.8	22.2	6.5	3.4	3.2	0.00	96.8
5	1216	4.9	78.0	50.9	22.7	6.1	3.3	3.1	0.00	96.9
6	913	3.7	83.1	47.9	23.4	5.8	3.2	3.9	0.00	96.1
7	700	2.8	87.0	46.8	24.8	5.5	3.1	5.1	0.00	94.9
8	523	2.1	89.9	41.8	24.9	5.3	3.2	7.3	0.00	92.7
9	345	1.4	91.8	40.7	23.7	5.0	2.8	5.5	0.00	94.5
10	268	1.1	93.3	37.5	25.0	5.3	3.2	8.6	0.00	91.4
11	212	0.9	94.5	36.7	26.0	5.4	2.9	5.7	0.00	94.3
12	163	0.7	95.4	34.5	23.9	5.2	3.1	10.4	0.00	89.6
13	144	0.6	96.2	35.4	24.0	4.9	2.9	11.8	0.00	88.2
14	109	0.4	96.8	36.3	26.8	5.5	3.1	8.3	0.00	91.7
15	87	0.4	97.3	30.5	24.4	5.4	3.5	12.6	0.00	87.4
16	65	0.3	97.6	34.0	24.8	5.3	3.1	6.2	0.00	93.8
17	62	0.3	98.0	28.5	25.8	5.3	3.0	17.7	0.00	82.3
18	54	0.2	98.3	29.4	27.0	4.6	2.7	14.8	0.00	85.2
19	42	0.2	98.5	28.3	28.2	5.4	3.1	16.7	0.00	83.3
20	44	0.2	98.7	29.8	27.3	5.5	3.5	11.4	0.00	88.6
21	42	0.2	99.0	31.3	27.1	5.9	3.6	11.9	0.00	88.1
22	24	0.1	99.1	28.2	28.6	5.8	3.1	4.2	0.00	95.8
23	23	0.1	99.2	28.1	23.9	4.8	3.6	8.7	0.00	91.3
24	26	0.1	99.4	24.0	22.7	5.9	3.6	11.5	0.00	88.5
25	12	0.0	99.5	37.0	26.9	4.3	1.9	25.0	0.00	75.0
26	6	0.0	99.5	29.2	29.3	3.9	2.0	16.7	0.00	83.3
27	10	0.0	99.5	33.5	30.2	3.7	3.0	40.0	0.00	60.0
28	8	0.0	99.6	45.0	25.9	4.1	2.9	12.5	0.00	87.5
29	7	0.0	99.6	31.3	31.5	4.4	2.1	14.3	0.00	85.7
30	5	0.0	99.7	16.8	18.1	5.6	1.3	0.0	0.00	100.0
31	10	0.0	99.7	26.4	26.3	5.1	1.6	10.0	0.00	90.0
32	9	0.0	99.8	17.5	26.7	5.9	2.1	33.3	0.00	66.7
33	9	0.0	99.8	20.7	15.9	5.4	1.7	11.1	0.00	88.9
34	7	0.0	99.8	22.4	20.5	4.8	1.6	28.6	0.00	71.4
35	3	0.0	99.9	32.3	36.1	6.3	1.7	0.0	0.00	100.0
36	6	0.0	99.9	14.5	14.4	4.2	1.5	50.0	0.00	50.0
37	2	0.0	99.9	38.0	1.4	5.7	3.1	0.0	0.00	100.0
38	4	0.0	99.9	26.2	4.6	4.0	1.7	0.0	0.00	100.0
39	6	0.0	100.0	24.0	11.0	4.3	1.4	16.7	0.00	83.3
41	1	0.0	100.0	13.0	0.0	5.3	0.0	0.0	0.00	100.0
44	1	0.0	100.0	1.0	0.0	5.5	0.0	0.0	0.00	100.0
50	5	0.0	100.0	21.0	34.4	2.3	3.6	60.0	0.00	40.0

Table 5. Statistical Analysis of DYNAMP's Predicted Temperatures for Data Points where DYNAMP is Greater than Measured Temperatures.

BASE STATION

T E M P E R A T U R E R A N K P E R C E N T A G E S

DYNAMP PREDICTS LOWER THAN MEASURED

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
1	2109	8.5	51.8	52.8	21.8	5.0	2.3	3.0	0.00	97.0
2	1421	5.8	66.7	50.0	22.1	4.4	2.2	4.8	0.00	95.2
3	918	3.7	76.4	47.0	23.7	3.9	2.1	8.0	0.00	92.0
4	595	2.4	82.7	44.8	23.6	3.6	2.1	10.3	0.00	89.7
5	412	1.7	87.0	42.7	24.0	3.5	1.9	11.9	0.00	88.1
6	297	1.2	90.1	39.7	24.1	3.4	2.4	21.9	0.00	78.1
7	235	1.0	92.6	38.6	23.2	3.2	2.4	24.7	0.00	75.3
8	163	0.7	94.3	34.8	25.6	2.9	2.3	33.7	0.00	66.3
9	129	0.5	95.7	30.3	24.0	2.8	1.7	36.4	0.00	63.6
10	100	0.4	96.7	29.4	22.7	3.1	2.0	34.0	0.00	66.0
11	69	0.3	97.4	32.5	24.4	2.4	1.4	36.2	0.00	63.8
12	52	0.2	98.0	32.4	27.1	2.4	2.0	46.2	0.00	53.8
13	49	0.2	98.5	36.8	27.2	2.0	1.5	44.9	0.00	55.1
14	37	0.1	98.9	43.0	29.5	1.8	1.6	48.6	0.00	51.4
15	22	0.1	99.1	38.3	27.9	2.0	1.6	59.1	0.00	40.9
16	22	0.1	99.3	34.0	26.2	1.6	1.6	59.1	0.00	40.9
17	14	0.1	99.5	34.3	19.9	1.2	1.4	71.4	0.00	28.6
18	12	0.0	99.6	37.9	29.9	1.3	1.3	58.3	0.00	41.7
19	5	0.0	99.7	31.7	30.9	2.6	1.6	40.0	0.00	60.0
20	5	0.0	99.7	45.5	18.0	2.5	1.1	0.0	0.00	100.0
21	4	0.0	99.8	47.0	14.3	2.6	0.7	0.0	0.00	100.0
22	4	0.0	99.8	44.1	17.8	3.0	0.4	0.0	0.00	100.0
24	1	0.0	99.8	37.0	0.0	1.8	0.0	0.0	0.00	100.0
25	3	0.0	99.9	62.7	11.0	4.0	4.0	0.0	0.00	100.0
26	2	0.0	99.9	10.1	2.8	8.1	9.8	50.0	0.00	50.0
33	3	0.0	99.9	78.3	11.2	2.5	0.5	0.0	0.00	100.0
42	1	0.0	99.9	19.0	0.0	2.3	0.0	0.0	0.00	100.0
43	1	0.0	99.9	69.1	0.0	2.8	0.0	0.0	0.00	100.0
50	7	0.0	100.0	46.8	16.7	5.7	2.2	0.0	0.00	100.0

Table 6. Statistical Analysis of DYNAMP's Predicted Temperatures for Data Points Where DYNAMP is Less Than the Measured Temperatures.

BASE STATION

T E M P E R A T U R E R A N K P E R C E N T A G E S

DYNAMP PREDICTS EXACTLY AS MEASURED

ERROR (C)	NO. PTS	PERCENT =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
0	2817	11.4	53.7	21.3	5.7	2.6	1.5	0.00	98.5

Table 6. (Continued)

velocities (see column labeled AV.SPEED) and when the wind is more in cross-flow than parallel flow (see column labeled AV.ANGLE).

C. Analysis of Remote Weather Data

The weather data collected at the test span and the four remote sites were used as input to DYNAMP and line temperatures were calculated for conditions at the five locations. Since the program can accurately predict the conductor temperature of a span located at each site, the predicted temperatures can be used to show the magnitude of temperature variations that will occur along a hypothetical transmission line that is routed past the five weather stations.

To illustrate how the conductor temperature can change from one span to another, the difference between the temperatures measured at the test span and those predicted at the other weather sites is plotted in Figure 20. These data show errors that could result when a weather station or line monitor located at one spot is used to predict the temperature of the conductor at another spot. For example 50 percent of the weather data collected at the test span used in DYNAMP produced temperatures that were within 2°C of the actual measured conductor temperature. If the weather station is moved one mile away, then 50 percent of the time the program is within 6°C of the temperature of the conductor at the test span. This type of information can be used to determine how closely spaced weather stations or monitors must be placed in order to produce a conductor temperature within a specified accuracy.

The weather data collected at the remote sites can also be used to show how various weather conditions will influence the predicted line

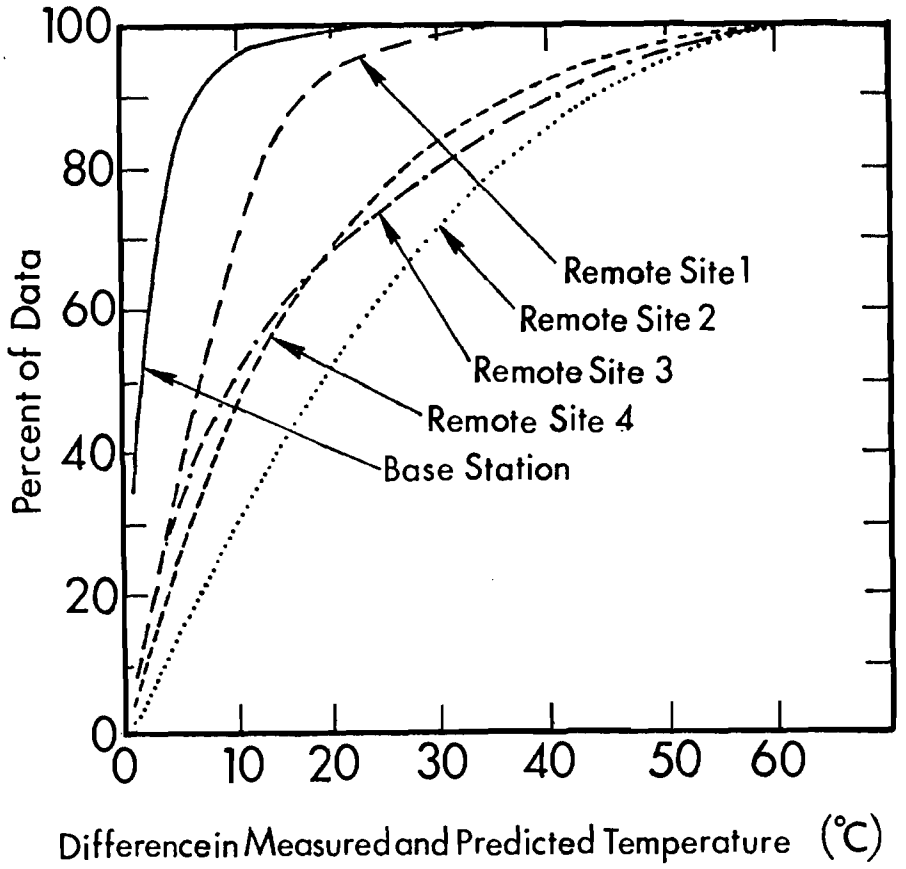

Figure 20. Program Accuracy as a Function of Distance Between Weather Station and Conductor Location.

temperatures. For example, Figure 21 shows how the difference between predicted and measured line temperatures at the five locations vary with the wind velocity. While the magnitude of the differences would change for different values of average line current, the trend shown in Figure 21 would still be the same. This figure shows that the difference in line temperature that exists between the five locations increases as the average wind velocity decreases. Therefore if a single station or monitor is expected to predict the temperature of another span one mile away (remote site 1) during calm wind conditions, errors that average 15°C can be expected. If a span is between 7 and 25 miles away (remote sites 2, 3 and 4) then differences in temperatures in excess of 30°C can be expected.

The curves in Figure 22 are similar to those that appear in Figure 21 except that the temperature differences are plotted as a function of wind angle instead of wind velocity. These curves show the general decrease in program or monitor accuracy as the wind blows down the axis of the conductor.

The data in Figures 20, 21 and 22 show that weather stations 2 and 3 have a poorer correlation than weather station 4, even though these two stations are closer to the test span than weather station 4. Weather data at remote sites 2 and 3 was stored on strip charts and had to be manually averaged and recorded. In addition, the data at remote site 2 could only be recorded on 15 minute intervals resulting in larger errors for that particular site. The best correlations resulted for those stations that have automatic data acquisition systems (base

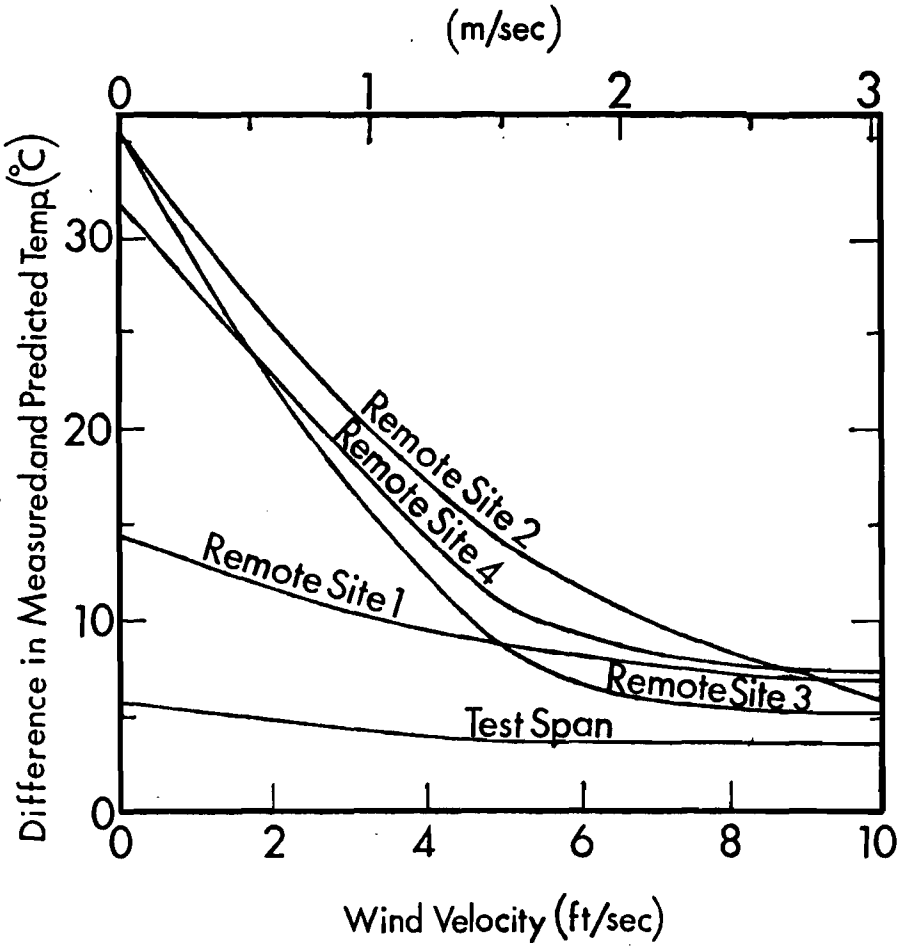

Figure 21. Program Accuracy as a Function of Wind Velocity for the Five Weather Stations.

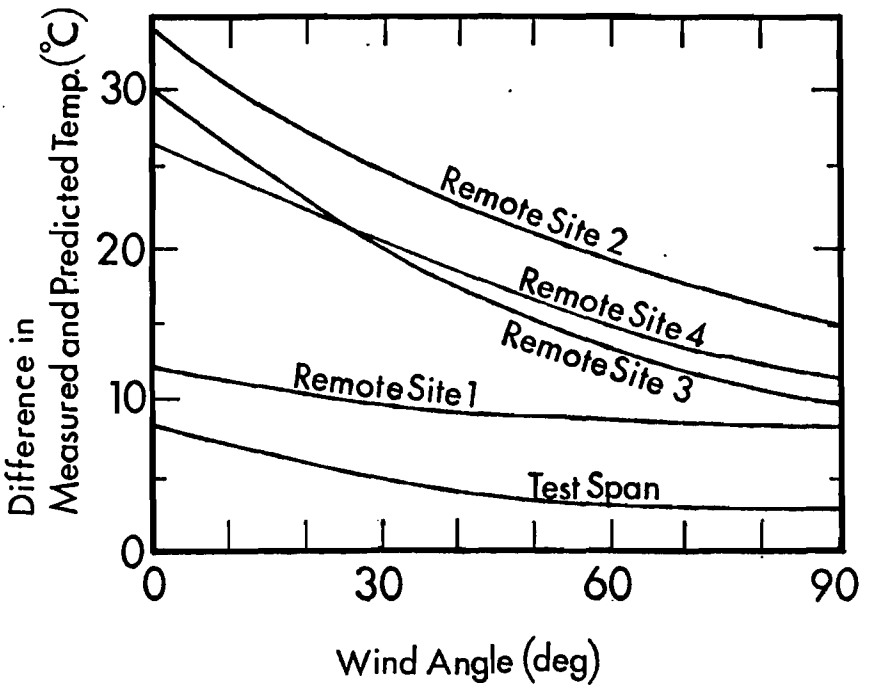

Figure 22. Program Accuracy as a Function of Wind Direction for the Five Weather Stations.

station and remote sites 1 and 4) because these stations were free of the errors that enter as a result of manual manipulation of the data.

D. Critical Span Analysis

During the last six months the study of the critical span concept has continued. Sensitivity parameters derived previously and reported in the last quarterly report have shown that the location and number of critical spans is dictated predominantly by weather conditions such as wind direction and wind speed. It has also been shown that it is unlikely that a single critical span exists along the length of a transmission line. Multiple critical spans are more likely and the location and number of critical spans move from spot to spot as a function time.

Several important conclusions regarding critical spans can be drawn from the sensitivity parameter study and the conclusions are verified by the data collected from the remote weather stations. On calm days the number of critical spans increases and their movement from span to span becomes more frequent. Also when the wind blows down the axis of a conductor, the number of critical spans and the movement of a critical span increases. These two facts imply that a thermal monitoring scheme can be expected to be the least accurate when the wind velocity is low and when the wind direction is down the conductor. Therefore, when weather and operating conditions place the greatest thermal demand on the system, the task of predicting the location of a critical span is most difficult. On days when the conductor is coolest, that is on days with relatively high wind speed flowing across the conductor, the critical span is easiest to locate.

Finally, the weather data collected at the base station and the four remote sites has shown that on very calm days line monitors and weather stations must be closely spaced (probably no more than one or two miles apart) to assure accurate conductor temperatures. On days in which the wind velocity is high and sustained, an accurate conductor temperature can be obtained from much more widely spaced monitoring equipment.

The results of the critical span study have been summarized in a paper entitled "Critical Span Analysis of Overhead Conductors" which has been submitted for review and publication in the IEEE Transactions. A copy of this paper is included in the appendix of this report.

E. Evaluation of the Line Monitor

The weather data and the conductor currents collected as part of the KEURP project were used to evaluate the accuracy of the line monitor and to compare the temperatures measured with the monitor to those values predicted by DYNAMP. The data in Figures 23 through 27 show typical results collected over a period of one month for three different conductor sizes.

Figure 23 shows some of the best temperature comparisons between the monitor and program. In general, the comparison was not as good as indicated in Figure 23 and the differences between predicted and measured temperatures were far greater than the data collected in Georgia. Weather conditions were somewhat different than experienced in Georgia because the Kansas wind velocity, in general, was much higher and fairly sustained compared to wind conditions in Georgia.

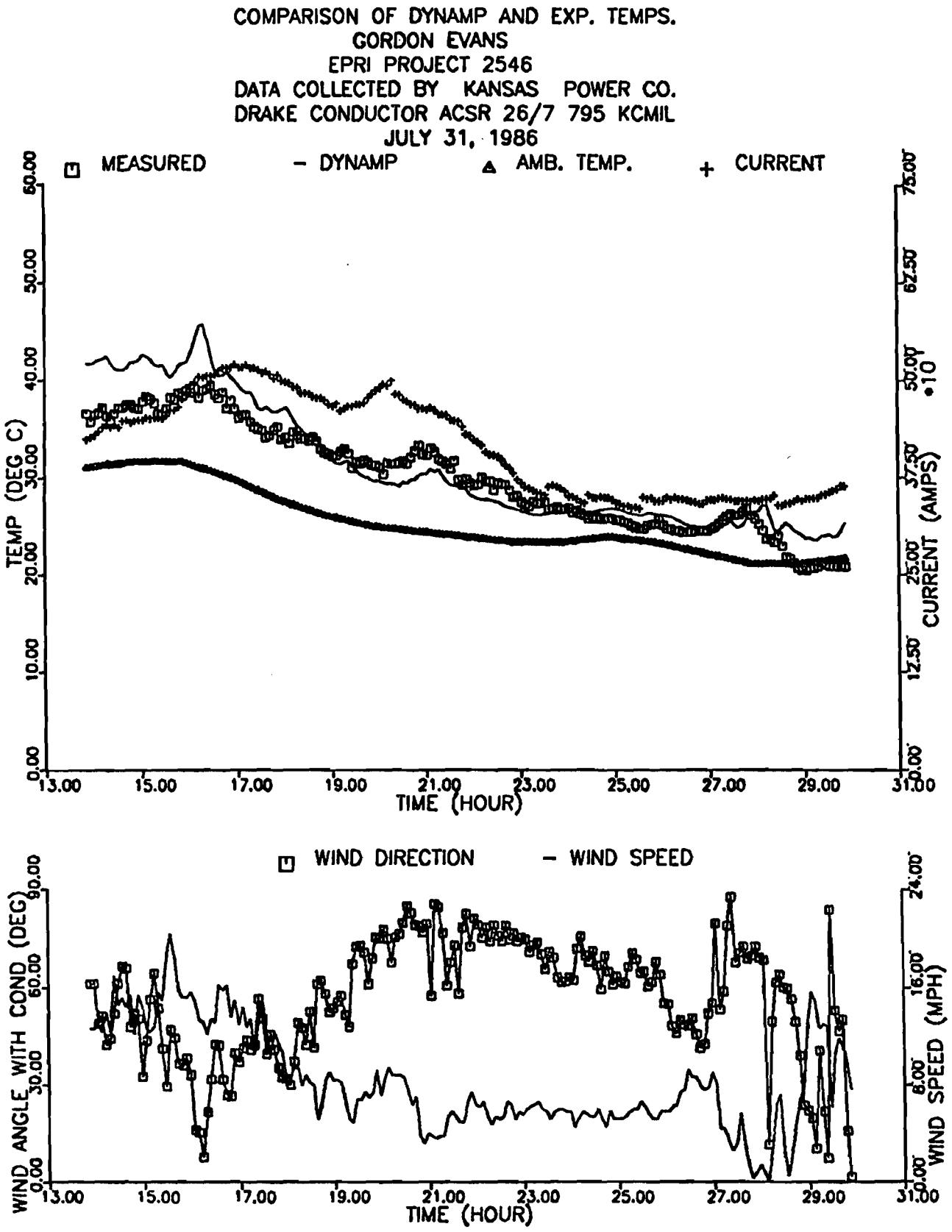

Figure 23. Comparison of DYNAMP and Line Monitor for KG&E Drake Conductor on July 31, 1986.

The temperatures in Figure 24 show more typical results and the sizeable errors that frequently occurred in the Kansas data. The difference between DYNAMP's predicted temperature and the line monitor's measured temperature exceeded 20°C on several occasions. This particular line was rather lightly loaded with a nearly constant current of approximately 1200 amps. For times between midnight and 6:00 am, the conductor was only a few degrees C above ambient temperature and during that period the difference in monitor and program temperatures was very small. About 7:00 am, the monitor began to indicate a temperature below the air temperature while the program predicted a temperature increase resulting from changes in the wind direction and velocity.

The curves in Figure 25 show a reasonable trend in the two temperatures, but the program is consistently 5-10°C higher than the monitor temperature. Once again the monitor measured a temperature below the ambient temperature for a brief period near midnight.

The curves in Figure 26 are a continuation of those in Figure 25. The monitor continues to measure a temperature lower than the surrounding air temperature for a period of over four hours. The program predicts a temperature that is consistently above the monitor temperature, although the trend in the two temperatures is nearly identical.

Figure 27 shows the data collected on September 25, 1986 with a Rail conductor. This particular figure shows the worst correlation between the program and monitor for all the data collected. Over a brief period of time the program predicted temperatures that were over

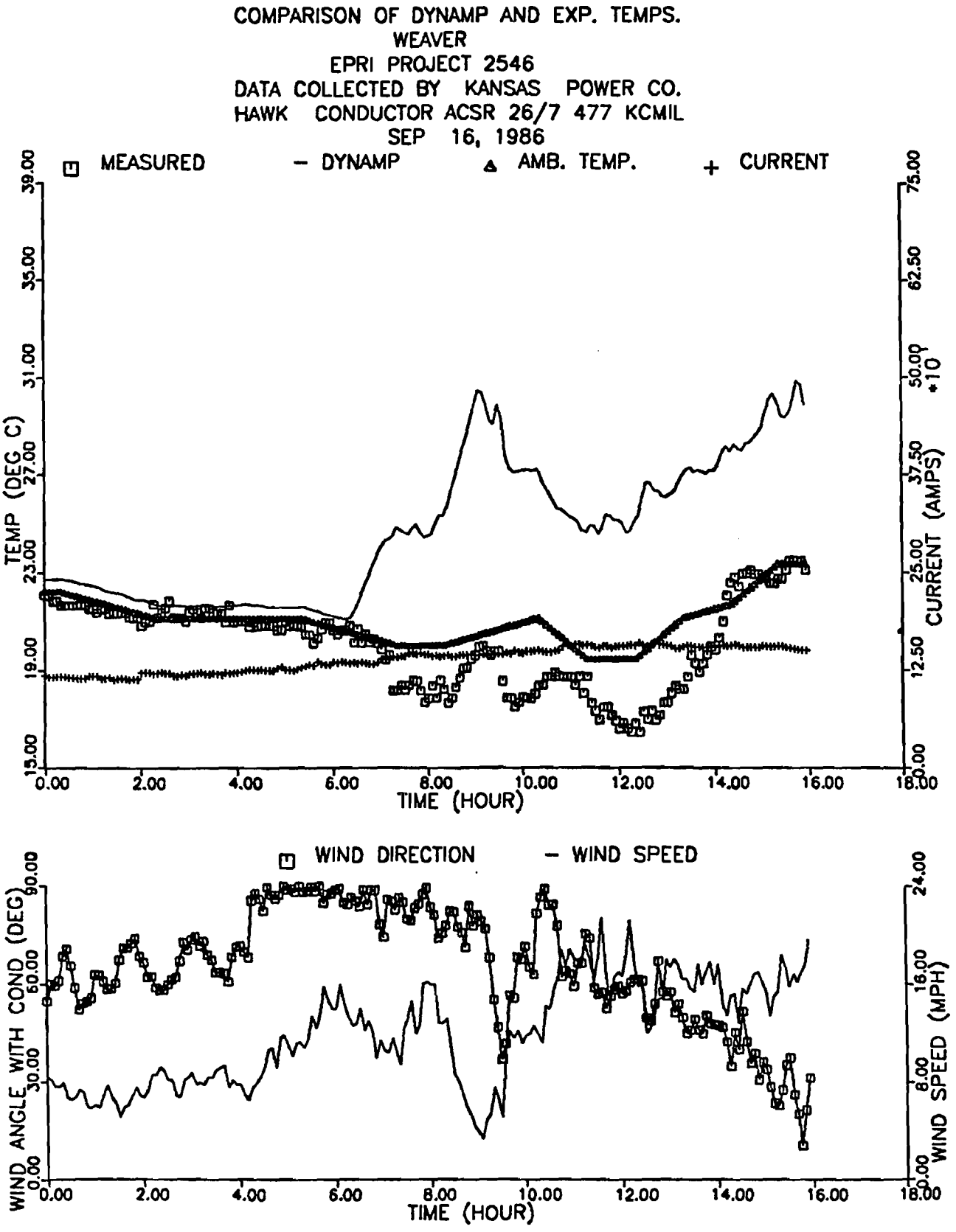

Figure 24. Comparison of DYNAMP and Line Monitor for KG&E Hawk Conductor on September 16, 1986.

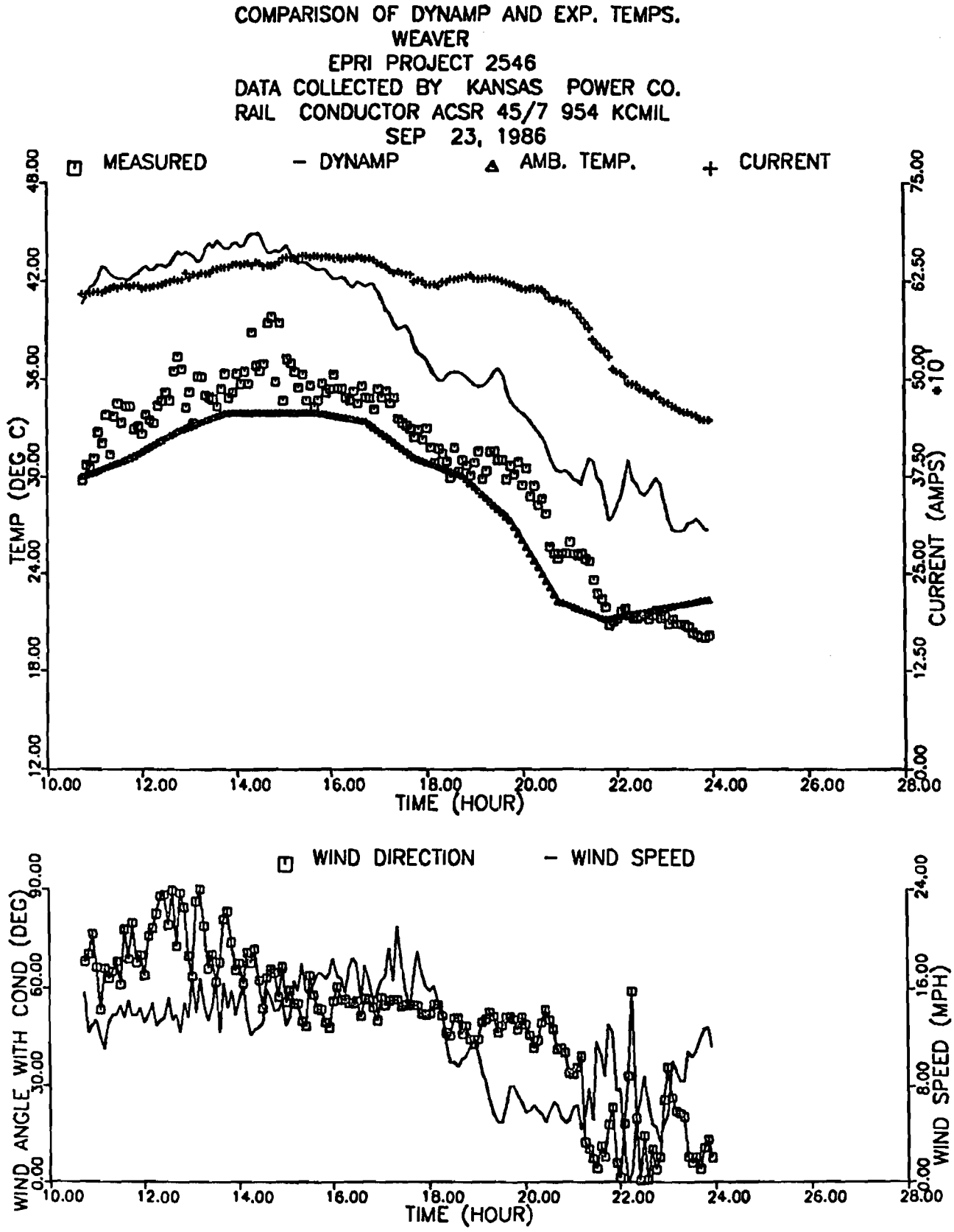

Figure 25. Comparison of DYNAMP and Line Monitor for KG&E Rail Conductor on September 23, 1986.

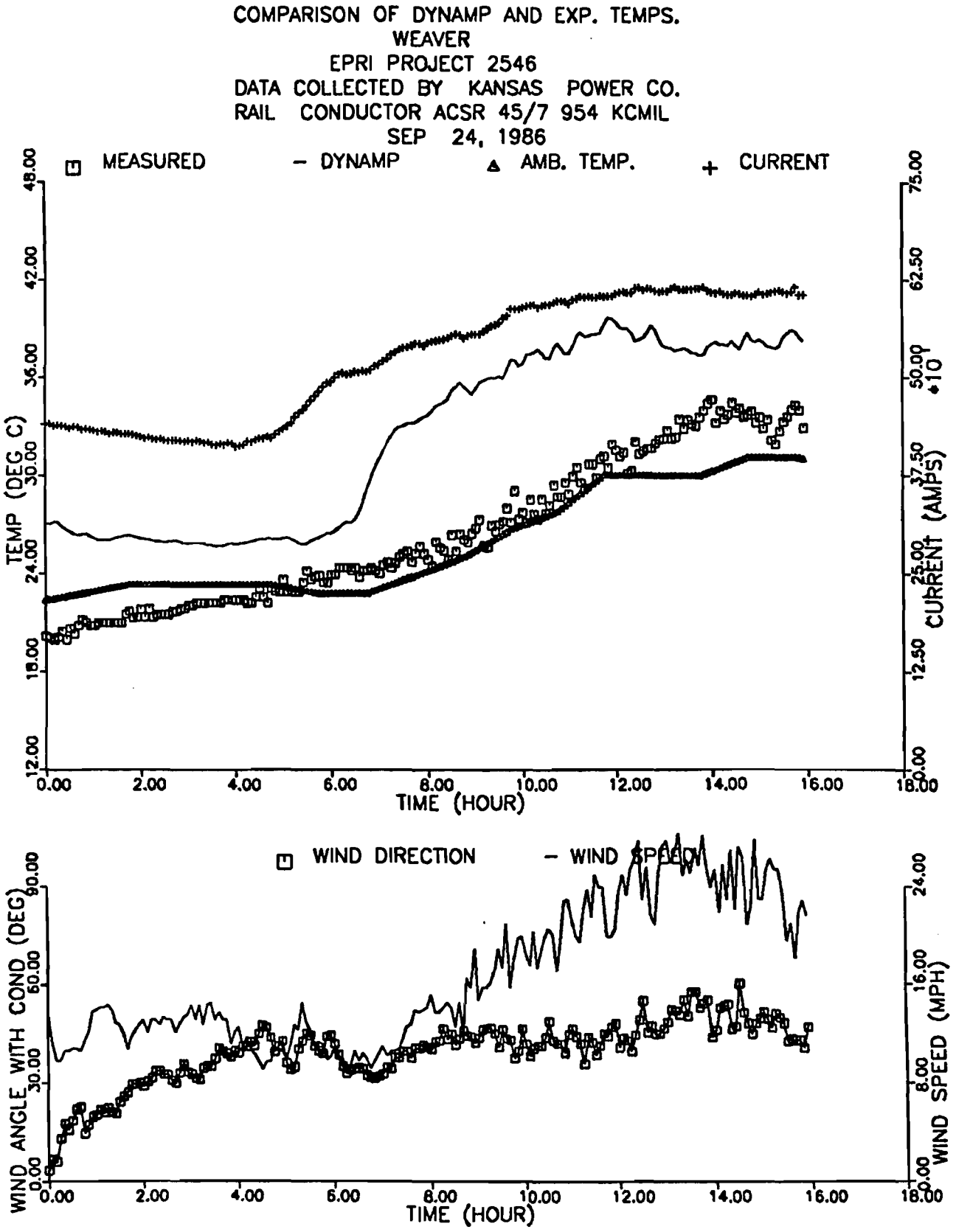

Figure 26. Comparison of DYNAMP and Line Monitor for KG&E Rail Conductor on September 24, 1986.

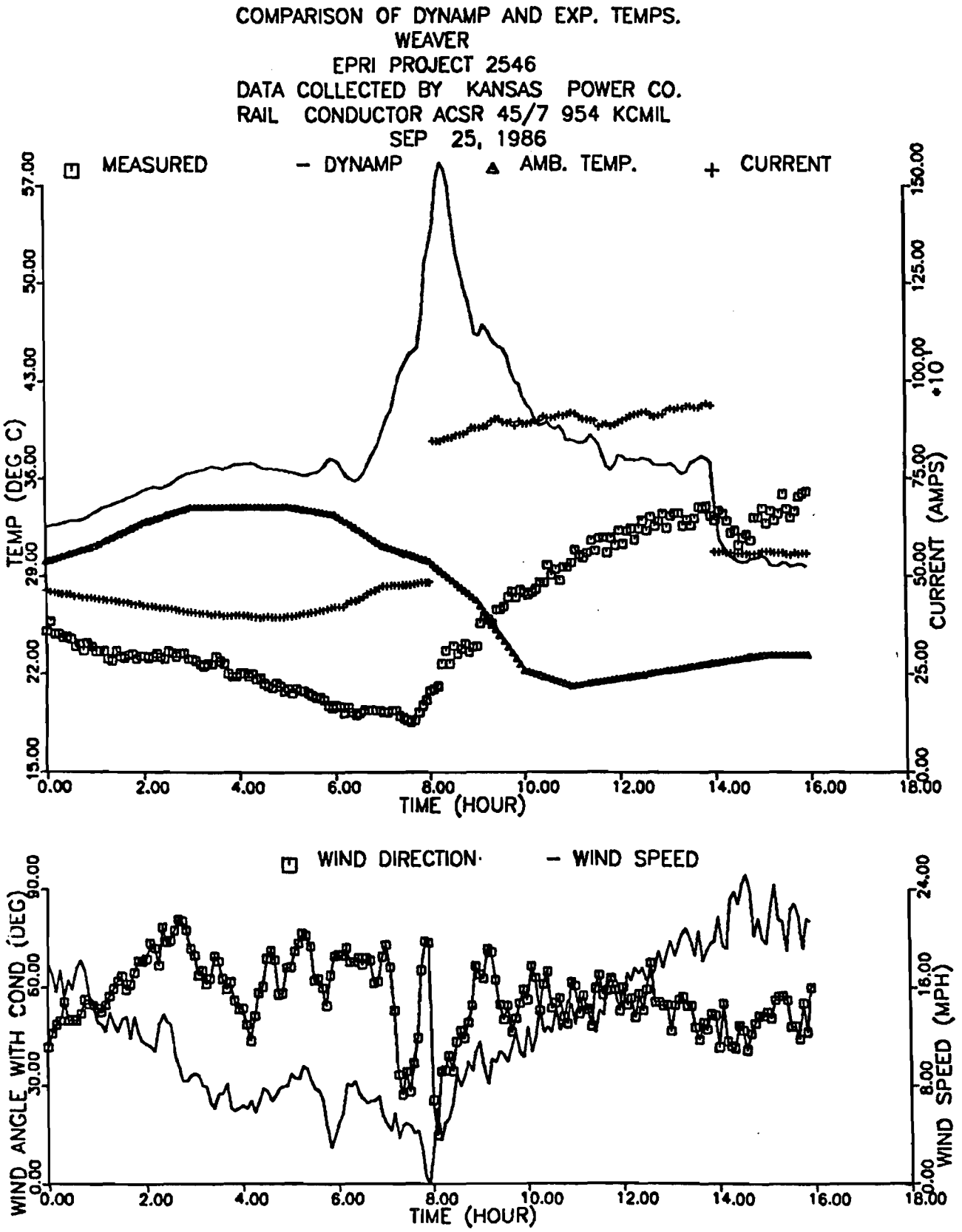

Figure 27. Comparison of DYNAMP and Line Monitor for KG&E Rail Conductor on September 25, 1986.

35°C greater than those measured by the monitor. The monitor measured conductor temperatures as much as 15°C below the surrounding air temperature, and it indicated a temperature lower than the air for a period of 9 hours. The program responded quickly to the step increase in conductor current from about 500 to 850 amps (nearly a tripling in heat generated) and a decrease in wind velocity which both occurred around 8:00 am. The monitor responded much more slowly and it eventually measures temperatures close to that predicted by the program nearly 6 hours after the step change in current had occurred.

APPENDIX

CRITICAL SPAN ANALYSIS OF OVERHEAD CONDUCTORS

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ABSTRACT

The concept of a critical span is an important one for a utility that has decided to monitor or calculate the real-time temperatures of their overhead transmission network. Theoretically, a critical span is that span or spans that operates at the highest temperature in a transmission system and thereby limits the amount of power that can be delivered by the circuit. Regardless of whether a utility has decided to measure conductor temperatures with line monitors or predict them with a computer model based on measured weather conditions, the concept of a critical span will help reduce the capital investment necessary to institute a thermal line monitoring scheme.

This paper identifies those factors that influence the location and number of critical spans. Quantities called sensitivity parameters are introduced and used to show how the critical span is influenced by weather conditions, conductor properties and conductor current. The weather conditions along the route of the line are shown to be the dominant factors which affect the conductor temperature and ultimately the number and location of critical spans.

The conclusions provided by the sensitivity parameters are verified by an experimental phase of the work. This effort consisted of a fully instrumented test span and five weather stations located at various distances from the test span. The weather data was used in a computer program that has the capability of predicting the real-time conductor temperature. The computer program provided predicted span temperatures at the five locations. In addition, a statistical analysis of the temperature data was used to examine the location of a critical span under various weather conditions. Temperature data collected at the test span, weather data from the five sites and the results of the sensitivity analysis all confirm the difficulties in locating critical spans particularly when they are governed to a large degree by local weather conditions that are highly variable and practically impossible to predict.

NOMENCLATURE

c_p	specific heat at constant pressure
D	conductor diameter
h	convective heat transfer coefficient
I	current
k	thermal conductivity of air
k_s	conductor skin effect
m	mass of a unit length of conductor
$Q"_{sun}$	incident solar energy per unit area
R_{AC}	AC resistance of conductor
R_1	DC resistance of conductor material
R_2	DC resistance of core material
R(20)	DC resistance of conductor at 20°C
α_1	conductor material temperature coefficient of resistance at T_1
α_2	core material temperature coefficient of resistance at T_2
T	conductor temperature
T_∞	air temperature
t	time
V	wind velocity
α	solar absorptivity of conductor surface
ϵ	infrared emissivity of conductor surface
ν	kinematic viscosity of air
ρ	density
σ	Stefan-Boltzmann constant
ϕ	angle between conductor axis and wind velocity vector
ω	angle between normal to conductor and wind velocity vector

INTRODUCTION

In order to more fully utilize the capacity of existing overhead lines, many major utilities are implementing techniques to determine conductor temperatures in real-time. If a utility chooses to measure the temperature of a line by installing thermal line monitors, it is faced with determining how many monitors should be used and where they should be located. Likewise, if the utility chooses to use computer modeling coupled with weather data to predict the conductor temperature, the number and location of weather stations need to be determined.

The emphasis on determining the real-time temperature of overhead conductors has lead to the introduction of the term "critical span". A critical span is an individual span or possibly several spans in an overhead transmission line that has the highest conductor temperature. The critical span therefore represents a thermal chokepoint which limits the amount of power that can be delivered by the circuit. The concept of a critical span is a particularly attractive one to an operating engineer who has the responsibility of economically and safely operating a transmission network, because it identifies the thermal weak link in each transmission line. By loading the system on the basis of the limiting critical span, the complex job of making load flow decisions without exceeding sag or loss of strength limits becomes, at least in theory, a much less demanding task.

If the temperature of a line is to be measured by thermal line monitors, then the monitors can, theoretically, be located at the critical spans. This approach would minimize the capital investment required to install a monitoring system. Likewise, if the conductor temperatures are to be predicted by using a computer model coupled with weather data measured along the route, then the weather station can be located at the critical span. Regardless of which technique for predicting the conductor temperature is eventually selected, the concept of critical span will help minimize the equipment costs.

The wind velocity and direction near the conductor are known [2,3] to be two of the most significant parameters in regulating the conductor

temperature. This fact suggests that any span along the route of the line which has a reduced wind velocity would be an obvious choice for a critical span. Lines that are routed through valleys, tall stands of trees or other areas where the wind is inhibited from circulating freely over the conductor would be prime candidates for a critical span. Furthermore, wind which blows down the axis of the conductor is much less effective in cooling the conductor than wind which blows across the conductor. Therefore spans which are oriented in a direction such that they are parallel to the predominant wind direction are also reasonable choices for critical spans.

While the concept of a critical span is quite simple, unfortunately it is difficult to put into practice. The temperature of an overhead conductor is a complex function of a wide variety of parameters including conductor size, current, electric resistance, weather conditions, line location and orientation, localized sheltering of the conductor and radiative properties of the surface of the conductor. Any computer model or line monitoring equipment must successfully account for all of these factors if they are expected to accurately predict the conductor temperature.

In order to predict the location of the critical span, one must know how sensitive the conductor temperature is to the numerous parameters which influence it. This requirement leads to the definition and derivation of sensitivity parameters which are discussed in the next section. These parameters will help determine whether a critical span can be located with any accuracy and repeatability.

SENSITIVITY PARAMETERS

The transient or real-time variation in the temperature of an overhead conductor can be determined by solving the following differential equation which is the result of an energy balance taken on a unit length of the conductor.

$$mc_p \frac{dT}{dt} = I^2R_{AC} + \alpha DQ''_{sun} - \epsilon\sigma\pi D(T^4 - T_\infty^4) - h\pi D(T - T_\infty) \qquad (1)$$

Equation 1 shows that the conductor temperature is a complex function of many factors. Obviously not all of the parameters affect the conductor temperature equally. Some have a major impact on the conductor temperature while others have practically no influence.

In order to quantify the effect of each of the variables on the conductor temperature, quantities which are called sensitivity parameters have been derived by using the steady-state form of Equation 1. Expressions for each of the sensitivity parameters result by taking derivatives of temperature with respect to each of the independent variables. This process produces the seven sensitivity parameters listed in Table 1. A detailed derivation of the sensitivity parameters is given in Reference 1.

The sensitivity parameters are convenient quantities which show how each variable influences the conductor temperature. Therefore, they will help to determine the location of critical spans. For example, the sensitivity parameter for wind velocity or $\partial T/\partial V$ quantifies changes in the conductor temperature with changes in the wind velocity. If the average value of $\partial T/\partial V$ is $-10^{o}C/(ft/sec)$ within a given range of operating conditions, then that conductor will experience a temperature decrease of $10^{o}C$ for a 1 ft/sec increase in wind velocity. Since wind velocities frequently can change on the order of several ft/sec, changes in conductor temperature are often in excess of $10^{o}C$ simply as a result of uneven wind distribution along the route of the conductor.

$$\frac{\partial T}{\partial V} = \frac{\pi D(T-T_\infty)\left[\frac{k}{\nu}10^{A}(a_1/Re_D + 2a/Re_D \log_{10} Re_D)\right](1.194 - \sin\omega - 0.194\cos 2\omega + 0.368\sin 2\omega)}{I^2\,\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial \phi} = \frac{k\pi 10^{A}\,(T - T_\infty)(\cos\omega - 0.388\sin 2\omega - 0.736\cos 2\omega)}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial \epsilon} = \frac{\sigma\pi D(T^4 - T_\infty^4)}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial \alpha} = \frac{-DQ''_{sun}}{I^2\partial R_{AC}/\partial T - 4\,\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial T_\infty} = -\frac{\pi Dh + 4\epsilon\sigma\pi DT^3}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial I} = \frac{-2IR_{AC}}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial Q''_{sun}} = \frac{-\alpha D}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

where $h = \frac{k}{D}10^{A}$ [5], $A = a_0 + a_1 \log Re_D + a_2(\log Re_D)^2$, $a_0 = -0.070431$, $a_1 = 0.31526$, $a_2 = 0.035527$

$$\frac{\partial R_{AC}}{\partial T} = \frac{k_s(R_1+R_2)[\alpha_1 R_1 R(20)_1 + \alpha_2 R_2 R(20)_2] - R_1R_2[\alpha_2 R(20)_2 + \alpha_1 R(20)_1]}{(R_1 + R_2)^2}$$

k, ν are assumed constant for small temperature changes

Table 1. Sensitivity Parameters.

In the graphs of the sensitivity parameters which follow, many of the independent variables were maintained constant. Unless specifically stated in the figures, a standard reference set of values was adopted for this purpose and is listed in Table 2. The correlation for convective heat transfer coefficient with velocity and direction was adopted from Reference 5.

Variable	Value
absorptivity	0.5
emissivity	0.5
ambient temperature	25°C
sun radiation	1000 W/m^2
wind direction	90° (normal flow)
wind velocity	2 ft/sec (0.61 m/s)
conductor types	Curlew, 54/7, 1033 kcmil Linnet, 26/7, 336 kcmil
current (75°C ampacity)	958 amps (Curlew) 492 amps (Linnet)

Table 2. Input Variable Reference Set.

The graph of the wind velocity sensitivity parameter, Figure 1, illustrates that the conductor temperature is far more sensitive to changes in wind velocity when wind conditions are nearly calm. At high wind velocities, a change in velocity has only a minor effect on the conductor temperature. Under normal conditions, it is far more common for the wind velocity to show large variations when conditions are calm. Therefore, calm weather conditions promote large variations in the local conductor temperatures as a result of variations in wind velocity from point to point along the route of the transmission line. As the wind velocity increases, the conductor temperature becomes less sensitive to changes in wind velocity and the temperature becomes more uniform.

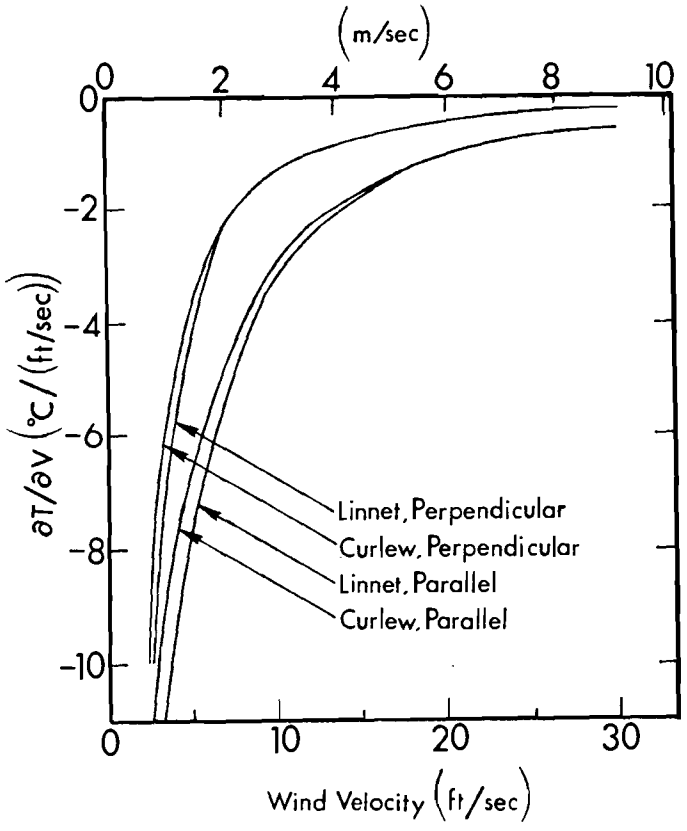

Figure 1. Wind Velocity Sensitivity Parameter

The graph of the wind direction sensitivity parameter shown in Figure 2 confirms that the conductor temperature is more sensitive to changes in wind direction as the wind blows down the axis of the conductor. This result implies that a wind oriented along the axis of the conductor will be accompanied by larger swings in the conductor temperature than when the wind blows across the conductor. Therefore, when the wind blows down the axis of the conductor, the location of a critical span will have a tendency to move from one location to another, while cross-flow wind will promote a more stable location for the critical span.

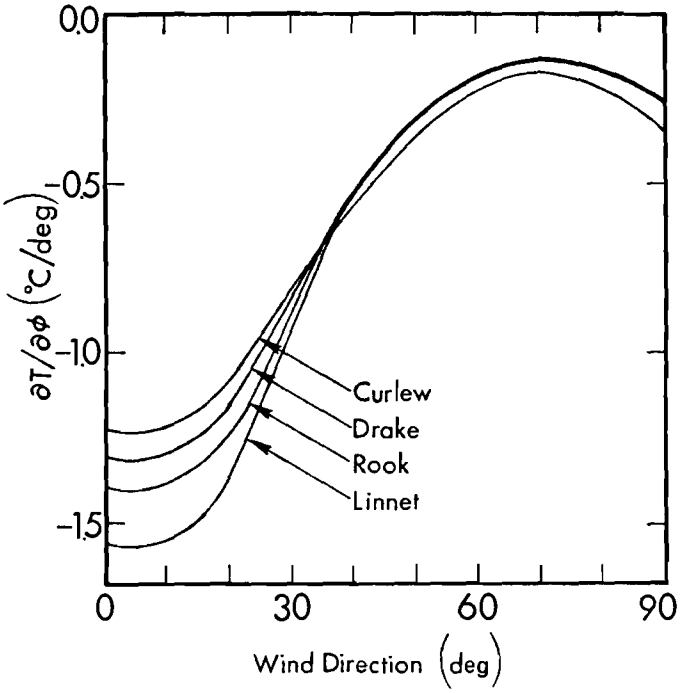

Figure 2. Wind Direction Sensitivity Parameter.

The current sensitivity parameter is plotted in Figure 3. These curves show how the current affects the temperature for a wide range of conductor sizes. When a conductor at a given load has the current changed by a fixed amount, the larger conductor will experience a smaller change in temperature, while the temperature of the smaller conductor will change a greater amount. At higher currents the sensitivity to a change in current is greater for all conductor sizes. Therefore, a heavily loaded small conductor will experience large temperature changes for relatively small changes in current. Large, lightly loaded conductors are less sensitive to changes in current.

The implication of the sensitivity parameters shown in Figures 1, 2 and 3 can be applied to the task of predicting the location of a critical span. The desire to locate a critical span will coincide with conditions that lead to a maximum conductor temperature. A system operator would have the

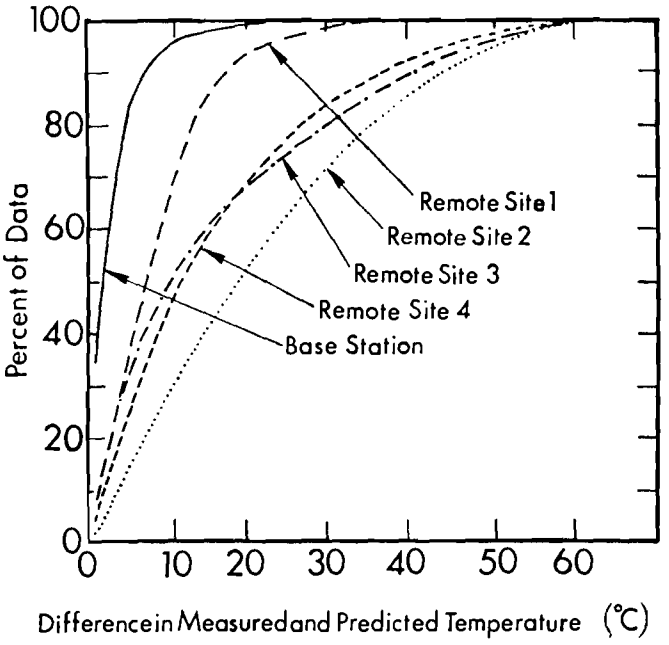

Figure 9. Errors in Predicted Conductor Temperature as a Function of Distance from Span.

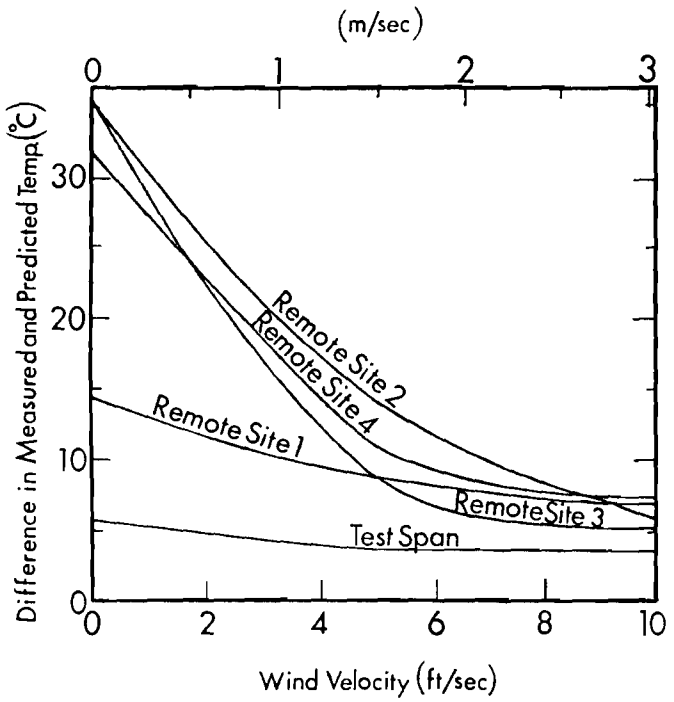

Figure 10. Errors in Predicted Conductor as a Function of Wind Velocity.

accuracy was quite good and it averaged less than 6°C. As the weather data was collected further from the test span, the accuracy was reduced, because the weather at the remote sites rarely coincide with that at the test site. Also the accuracy decreased as the wind velocity decreased because the line temperature became more sensitive to changes in the wind and the small variations in wind velocity from location to location produced large changes in the conductor temperature. The data in Figure 10 shows that if a single monitor is expected to predict the temperature of another span about 1 mile away (remote site 1) during conditions of no wind, errors of about 15°C can be expected. If it is expected to predict the temperature of a span between 7 and 25 miles away, errors in excess of 30°C can be expected.

The curves in Figure 11 are similar to those which appear in Figure 10 except that the temperature differences are plotted as a function of wind angle instead of wind velocity. These curves show the general decrease in program or monitor accuracy as the wind blows down the axis of the conductor. As expected, the variation in conductor temperature increases as the distance to the weather station increases.

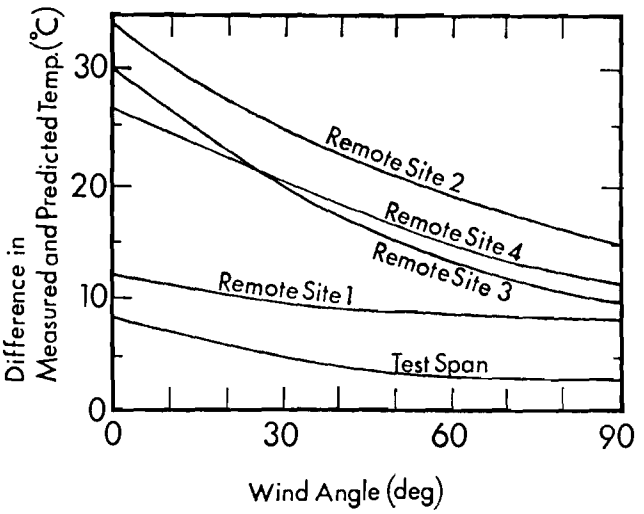

Figure 11. Errors in Predicted Conductor Temperature as a Function of Wind Direction.

SUMMARY

The sensitivity analysis, the weather data collected at the five weather sites and the computer predicted temperatures for the five locations all confirm the following conclusions:

1. It is unlikely that a single critical span exists in a transmission line. Multiple critical spans are more likely and the location and number of critical spans move from one spot to another as a function of time.
2. The location and number of critical spans is predominantly dictated by weather factors.
3. On calm days the number of critical spans increases and their movement from span to span becomes more frequent.
4. Wind that blows down the axis of a conductor causes an increase in the number of critical spans and promotes movement in the critical span from one location to another.
5. Thermal line monitors and weather stations coupled with computer programs will be least successful in predicting the critical temperature of a transmission line when the average wind velocity is low, when the wind blows down the axis of the conductor and when the current levels in the circuit are high.
6. Line current and weather conditions which produce the greatest thermal demand on the system (resulting in the highest average conductor temperature) are identical to those that make the location of the critical spans most difficult to predict.

7. On very calm days line monitors and weather stations must be closely spaced, probably no more than 1-2 miles apart for the type of terrain in this study, to assure accurate conductor temperatures. When selecting monitor locations, each utility should consider its own terrain and evaluate how the spacing will affect the accuracy of a real-time line monitoring system. On days in which the wind velocity is high and sustained, an accurate conductor temperature can be obtained from much more widely spaced monitoring equipment.

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Section 1

INTRODUCTION

This User's Manual describes the operation of a computer program which models the transient ampacity of overhead conductors. The program was developed at the Georgia Institute of Technology and its accuracy has been verified by comparing the predicted conductor temperatures with values measured at Georgia Power Company's Research Center and temperatures measured in a separate study sponsored by Kansas Electric Utilities Research Program and carried out by Kansas Gas and Electric Company. The resulting program is called DYNAMP for DYNamic AMPacity of overhead conductors.

DYNAMP can perform both steady-state and transient ampacity calculations. There are three program options. The first program option involves a steady-state model which calculates a single value of the conductor temperature for constant weather conditions and a constant line current. The program also calculates ampacity for a given value of conductor limiting temperature. This type of model has been traditionally referred to as the House and Tuttle method. The second program option consists of a transient model for real-time conductor operation and it calculates instantaneous conductor temperatures when the conductor experiences varying current levels and weather conditions. The third program option provides predictive temperature calculations based on emergency situations that can arise from a sudden current overload on the line.

The real-time calculations are based upon ambient weather conditions and are frequently updated so that real-time values of wind speed, wind direction and the ambient temperature are used as input data. The effect of the changing weather conditions and conductor current is incorporated into the thermal analysis by accounting for the thermal capacitance of the conductor. The contribution of the solar loading on the conductor temperature is automatically considered in a separate subroutine which calculates the clear-sky incident solar energy at the specified location of the conductor.

The program has the capability of predicting real-time temperatures for seven different types of conductors. Composite conductors such as ACSR as well as

conductors consisting of either all-aluminum or all-copper strands can be modeled. A single parameter is used to specify the type of conductor. The program execution is simplified by the use of a property program that automatically enters five physical constants of the conductor when the user specifies the conductor code name. Most of the common overhead conductors are included in this property subprogram and its use greatly simplifies the input of conductor data into the program.

The main program and all subprograms contain numerous checks on internal calculations performed within the program. If the program encounters unusual values for calculated quantities or for input variables, a series of diagnostic messages are printed on the screen. In addition, a series of help files are appended to the program to aid the user in interpreting the use and operation of the program.

DYNAMP is designed to operate on an IBM-PC an it is part of the TLWorkstation software. The user interacts with the program through a user-friendly front end program written by Power Computing Corporation. This program facilitates the operation of DYNAMP and it simplifies the program instructions. The remainder of this manual describes the commands necessary to operate the real-time ampacity program.

Section 2

PROGRAM INPUT

GENERAL INFORMATION

Input to DYNAMP consists of 24 variables when steady-state calculations are required, 26 variables when transient or real-time ampacity values are required and 27 variables when the predictive program is specified. This section briefly describes each of these input variables. It is not necessary that the user know the variable names to execute the program, but he should be familiar with the type of information that the variables contain. The input information is subdivided into eight groups with each variable in a single group providing a similar function. The eight groups are:

1. Run Type: One variable which selects major program options such as steady-state, transient and predictive calculations of the conductor temperature and one variable which specifies the limiting temperature used in both the steady-state and predictive program options.
2. Conductor Properties: Seven variables which specify the geometry of the conductor.
3. Date and Time: Four variables used to specify the time sequence for calculation of the solar input to the conductor.
4. Line Location: Five variables that specify the location and orientation of the conductor.
5. Radiation Properties: Two variables used to specify the radiative properties of the conductor.
6. Transient Variables: Two variables used to control the transient operation of the program.
7. Predictive Variables: One variable used to control the predictive operation of the program.
8. Current and Weather: One value for conductor current and three variables which describe the weather conditions at the location of the conductor. One value for each quantity is required for steady-state calculations, while a series of currents and weather properties is expected for real-time and predictive calculations.

When the user specifies steady-state ampacity calculations, input values for both the Transient Variables group and Predictive Variables group are not necessary. When transient calculations are called for, only the values for the Predictive Variables are not required. When predictive calculations are specified, the user must provide input values for each of the eight groups of data.

DESCRIPTION OF INPUT VARIABLES - STEADY-STATE CALCULATIONS

The first item of input information the user is asked to supply when first running the program is the Run Type. If the steady-state option is selected, then the user will be sequentially led through the remaining input information necessary to operate the steady-state program option. This section briefly describes the required input information for steady-state calculations.

1. Run Type

If the steady-state program option is selected, the user will be asked to supply a limiting conductor temperature. The program will then calculate the conductor ampacity for this limiting temperature and the specified weather conditions.

Limiting Temperature (Degrees C)	This temperature should be the maximum conductor temperature in degree Celsius. The selected value should be between 20°C and 200°C.

2. Conductor Properties

The user can select the conductor properties in one of two ways. If the code name of the conductor is specified and it corresponds to one cataloged in a properties subprogram, all properties of that conductor will be automatically loaded into the program. If a conductor name is not specified, or if one is and it does not correspond to one with stored properties, then the user must manually enter each property. A list of all conductor code names contained in the property subprogram is included in the Appendix.

Code Name	The code name specifies a particular conductor. Typical example code names are DRAKE, FALCON, MARIGOLD, etc.
Conductor Type	Must be one of the seven types listed in the table below.

Type	Conductor Material	Core Material
ACSR	1350-H19 Aluminum	Steel
AAC	1350-H19 Aluminum	1350-H19 Aluminum
AAAC	6201-T81 Aluminum	6201-T81 Aluminum
ACAR	1350-H19 Aluminum	6201-T81 Aluminum
All Copper	Hard drawn Copper	Hard Drawn Copper
Alumoweld	1350-H19 Aluminum	Alumoweld
AAAC	5005-H19 Aluminum	5005-H19 Aluminum

Note: Composite conductors, such as ACSR conductors, consist of two layers of different materials. The inner supporting material is referred to as the "core" material. The outer current-carrying material is referred to as the "conductor" material.

Conductor Diameter (Inches)
The outside diameter of the conductor.
Must be greater than the strand diameter and less than 3.0 inches.

Conductor Strand Diameter (Inches)
The diameter of individual conductor strands.
Must be greater than zero but less than 0.5 inches.

Core Strand Diameter (Inches)
The diameter of individual core strands.
This value is ignored for conductors with no core strands (that is, conductors for which the core strands and conductor strands are made of identical materials, as for example AAC, AAAC, and all copper conductors).
This value must be greater than zero but less than 0.5 inches.

Number of Conductor Strands
The number of strands of conductor material (not including the core strands).
This integer value must not exceed 300 and must be greater than 0.

Number of Core Strands
The number of strands of core material.
This integer value must not exceed 300.

A.C. Resistance (Ohms/mi @ 25 C) — The a.c. resistance of the composite conductor in ohms per mile at 25 degrees Celsius. This value must be greater than 0.

3. Date and Time

The four date and time variables are used in a subprogram that calculates the incident solar energy on the conductor. Each of these four quantities are integer values.

Month — Month of the year.

Day — The day of the month.

Time — Twenty-four hour clock time as hours:minutes. (midnight = 00:00, noon = 12:00, 3 pm = 15:00, etc.) Use standard time only, not daylight savings time.

Time Zone — One of the four time zones in the continental U.S.: Eastern, Central, Mountain, or Pacific. (If you wish to calculate temperatures for a conductor that is not located in any of these time zones (i.e. Hawaii, Alaska) then choose one of the four time zones in the continental U.S. and calculate the twenty-four hour clock time at the conductor location for the time-zone chosen -- e.g. if the conductor is located in Hawaii and if calculations are desired for noon Hawaii time, then the time that should be us d if the Pacific time zone is chosen would be 14:00.)

NOTE: Values for the time variables are needed so that the program can correctly calculate the solar heat added to the conductor. For real-time calculations these values specify the time for the initial set of weather and current values. For steady-state calculations the time variables specify the time at which a single steady-state conductor temperature is calculated.

Line Location

Latitude (Degrees) — The latitude of the conductor location in degrees north from the equator. This value should be

between 0 and 90 degrees. (See map shown in Fig. 2-1 for values.)

Longitude (Degrees) — The longitude of the conductor location in degrees east of Greenwich, England. This value should be between 0 and 360 degrees. (See map shown in Figure 2-1 for values.)

Elevation (Feet) — The elevation of the conductor above mean sea level. This value should be between 0 and 25,000 feet.

Conductor Azimuth (Degrees) — The conductor azimuth is the angle in degrees measured clockwise from a vector pointing north to the vector which is the horizontal projection of a line passing through the axis of the conductor. The conductor azimuth must be between 0 and 180 degrees. Examples: a conductor oriented from the northwest to the southeast has an azimuth of 135 degrees. An east-west line has an azimuth of 90 degrees. The azimuth of a north-south line can either be 0 degrees or 180 degrees.

Note: The end of the conductor used to determine the azimuth will also be used to determine the conductor inclination.

Conductor Inclination (Degrees) — The conductor inclination is the angle in degrees between a line through the conductor axis and the horizontal plane. This angle should be between -90.0 and +90.0 degrees. If the end of the conductor used to determine the conductor azimuth lies below the horizontal plane, then the conductor inclination is negative. If the end of the conductor used to determine the conductor azimuth lies above the horizontal plane, then the conductor inclination is positive. (Examples: If the end of the conductor is 33 degrees below the horizon, then the inclination angle is -33 degrees. If the end of the

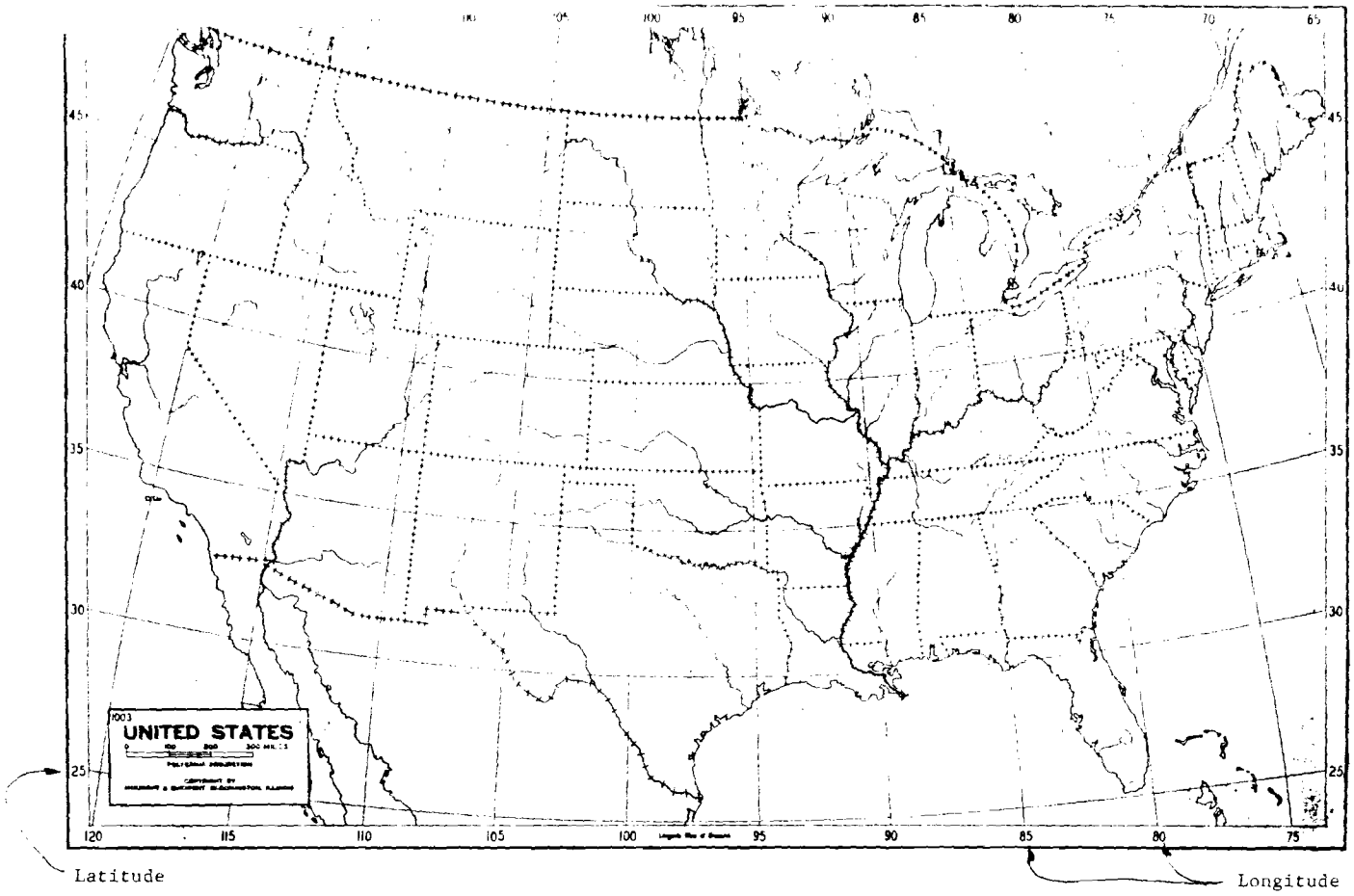


Figure 2-1. Latitude and Longitude for Continental U.S.

conductor lies 33 degrees above the horizon, then the inclination angle is +33 degrees. If the conductor is horizontal, the inclination angle is 0 degrees.)

b. Radiation Properties

The user must specify two radiative properties of the conductor material: solar absorptivity and infrared emissivity.

Solar Absorptivity The fraction of incident solar radiant energy that is absorbed by the conductor surface. This value should be between 0 and 1. Recommended values are given in tables below.

COPPER CONDUCTORS	
Oxidation Level	Absorptivity
None	0.23
Light	0.5
Normal	0.7
Heavy	1.0

ALUMINUM CONDUCTORS		
Years in Service	Line Voltage	
	< 15 kV	> 15 Kv
0	0.43	0.43
5-10	0.55	1.00
10-20	0.66	1.00
20-30	0.80	1.00
> 30	0.90	1.00

Infrared Emissivity The ratio of infrared radiant energy emitted by the conductor surface to the infrared radiant energy emitted by a blackbody at the same temperature. This value should be between 0 and 1. Recommended values are given in tables below.

COPPER CONDUCTORS	
xidation Level	Emissivity
None	0.03
Light	0.3
Normal	0.5
Heavy	0.8

ALUMINUM CONDUCTORS		
Years in Service	Line Voltage	
	< 15 kV	> 15 Kv
0	0.23	0.23
5-10	0.35	0.82
10-20	0.46	0.88
20-30	0.60	0.90
> 30	0.70	0.90

6. Current and Weather Conditions

The conductor current in amperes is the first input value in this set. It is followed by three weather parameters which are ambient air temperature, wind direction and wind velocity. When steady-state conditions are specified, only a single set of current and weather conditions is permitted.

Current (amps)	Line Current in amperes.
Air Temperature (degrees Celsius)	Air temperature (between -50 and 50 Deg C).
Wind Direction (degrees)	Wind direction in degrees measured clockwise from due north (between 0 and 360 degrees).
Wind Velocity (ft/sec)	Wind velocity near the conductor. This value must be between 0 and 85 feet per second.

DESCRIPTION OF INPUT VARIABLES - TRANSIENT CALCULATIONS

In response to the input of the Run Type, the user may specify the transient program option. For this option, the program calculates transient (real-time) conductor temperatures based on a set of weather conditions and conductor currents that change with time.

When the transient program option is selected, the input variables to the program are identical to those described above for steady-state calculations except for two changes. The user must specify a series of weather conditions and conductor currents instead of a single value for each, and the user must specify a time interval for the data by selecting values for the Transient Variables. These additional input values are described below.

Transient Variables

The first of these two variables is used to determine the time interval between each set of weather and current data. The second variable determines how frequently the transient temperature of the conductor is printed.

Time Interval (Minutes)	The time interval between each set of current and weather conditions. This value must be between 1 and 30 minutes.

Printing Interval (Minutes)	The time interval between the printing of each conductor temperature. This value must be between 1 and 30 minutes. It is usually desirable, although not necessary, to have this value equal the "Time Interval" defined above.

In the transient mode the program automatically calculates the conductor temperature for the first set of weather and current conditions at the time corresponding to the date and time given in the Date and Time input group. The program then increments time by a value equal to Time Interval and uses the second set of weather and current data. The program continues to increment the time by a value equal to Time Interval and it calculates the temperature for each set of weather and current data as long as data is available. The program terminates when no further data is found.

The user can print conductor temperatures on a time interval equal to Printing Interval. By selecting a print interval less than the time interval for the weather and current data, the user can print temperatures that are closely spaced in time. On the other hand, if output temperatures are needed at widely spaced time intervals, the user can select a larger value for the Printing Interval.

DESCRIPTION OF INPUT VARIABLES - PREDICTIVE CALCULATIONS

The predictive program option permits the user to predict the temperature of the conductor when it is subjected to a step change in current. The user must specify the value of overload current and the program returns the time required for the conductor to reach an emergency limiting temperature which is also specified by the user in the Run Type data group.

The scheme used by DYNAMP for calculating an emergency time is shown graphically in Figure 2-2. The theory behind this calculation stems from the desire to give the operating engineer a single value of time so that he can quickly take corrective action in the event of an emergency current overload. If this predicted time is very short, say between a few seconds or a few minutes, then the operator knows he is dealing with a heavily loaded line with practically no spare thermal capacity. If an emergency overload occurs on that particular line, then switching of current to other circuits will be necessary or, otherwise, the circuit will quickly become overheated. On the other hand, if the program predicts an emergency time that is closer to an hour or greater, then the line is either lightly loaded and it has a relatively large capacity to respond to an overload in current without reaching a dangerous temperature level.

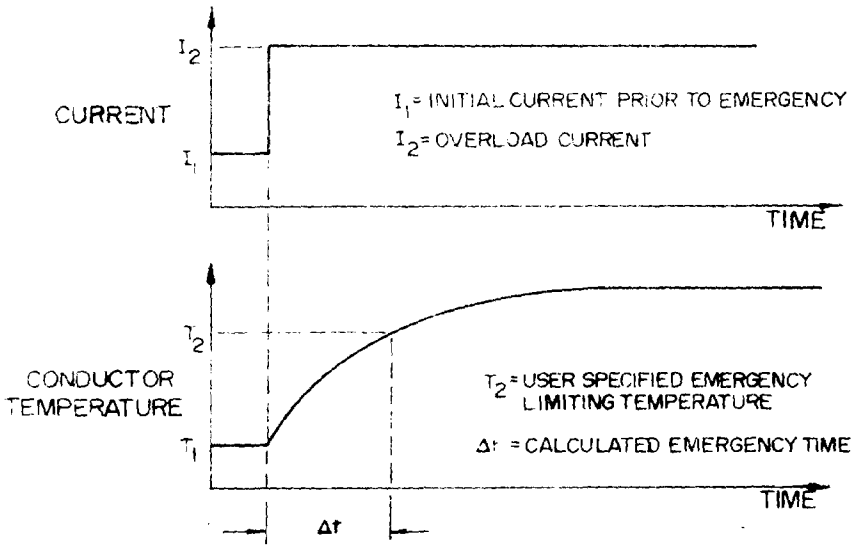


Figure 2-2. Predictive Calculational Scheme Used by DYNAMP.

l of the input variables described for steady-state calculations and for ansient calculations are required when the user selects the predictive mode of eration. In addition to these input values, the user must also select one citional input variable when the predictive program option is chosen.

Predictive Variables

Overload Current (Amps)	The program assumes that there will be a step change from the normal current to the overload current.

n the program is in the predictive mode, the time required for the conductor to ch the limiting temperature specified in the Run Type Variables is calculated the current increases in a step fashion to the overload current. This ulated time internal is shown as Δt in Figure 2-2.

Section 3

DYNAMP OPERATION

GENERAL

DYNAMP FORTRAN program is part of the TLWorkstation Software Package. The user executes the interactive DYNAMP software system through a series of interactive menus and prompts which are displayed on the screen. With this system, the user can create and edit input data files, rename data files, execute the DYNAMP FORTRAN program, and perform several other tasks.

Menus

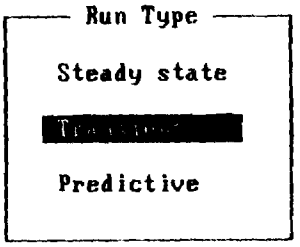
The menus are designed so that each is responded to in a similar fashion. When a user is presented a menu, the following instructions will be displayed at the bottom of the screen.

Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

These instructions can be used to select a choice from the menu. For all menus, the method is the same. Selections are made by positioning a highlighted cursor over the desired selection. The cursor is moved from one selection to the next by pressing the space bar or by pressing the cursor keys [↑ ↓ ← →]. Once the cursor is positioned at the desired selection, the user should press the [Enter] key. If the user desires a better understanding of the items on the menu, the [F1] key should be pressed for help.

In the example shown below, the user is being asked to select between steady-state, transient, or predictive run types.

DYNAMP



Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

The cursor is presently positioned over the *"transient"* selection. If the user presses the [Enter] key, the program will assume the user wishes to calculate conductor temperatures for transient operation.

Prompts

When the user is asked to answer a question (prompt), the program will provide a *"field"* to the right of the question for the response.

Conductor code name.....: [redacted]

In the example above, the user is prompted for the conductor code name. The field, which is shown as a highlighted block, will appear on the computer screen.

To aid in the response to a prompt, the following instructions are displayed at the bottom of the screen.

Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

If the user wants information on the input data field, the [F1] key should be selected. To return to the previous menu or screen display, the [Esc] key should be selected. To move to the next prompt (next field), the [Enter] key should be pressed.

Data Files

There are three different types of data files:

1. raw input data
2. documented input data
3. output data.

The input data files are created and maintained through features under *"Data Management and Utilities"* in the Module Menu. These data files contain the raw input data that will be used when the DYNAMP program is executed. This raw input data consists of the variable groups discussed in earlier sections of this manual. The user cannot print raw input data to a printer, but will be able to edit raw input data files by using editing and creating procedures to be described later.

Formatted input data files are formatted versions of raw input data. These data files are not used to execute the DYNAMP program. They are used to display the contents of raw input data files either by printing to the screen or to the

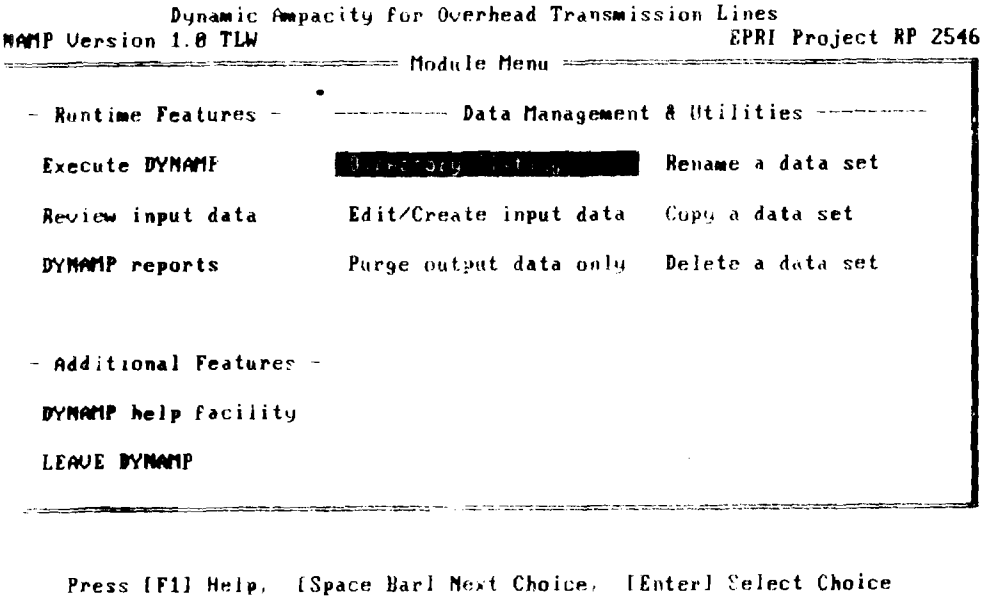
printer. The procedure used to create and print formatted input will be described later.

Output data files contain DYNAMP program results. An output data file is created by execution of the DYNAMP program. This file contains not only the thermal analysis output but also the formatted input data of the raw input data file that was used in executing the DYNAMP program.

These data files are automatically grouped into "data sets". Each data set will contain one and only one raw input data file. Each data set may also contain a formatted input data file and/or an output data file. Each formatted input data file and output data file will correspond to the raw input data file within that data set and will have the same name as the raw input data file. Hence, the data set will have that name also.

GETTING STARTED

After selecting DYNAMP from the TLWorkstation Master Menu, the following Module Menu will appear on the screen. The Module Menu is the base from which a DYNAMP session will be operated.



From this menu, the user selects one of several features:

1. Data Management and Utilities
2. Runtime Features
3. Additional Features

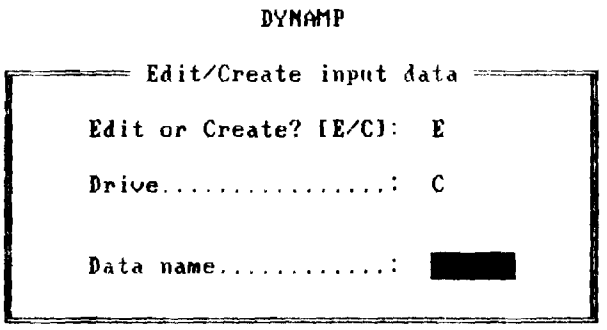
Data Management and Utilities enables the user to perform tasks such as editing input files, creating input files, purging files, and other data management tasks. Runtime Features allow the user to execute the DYNAMP program and to obtain printed copies of output.

Note that before the user can execute the DYNAMP program, an input data file must have already been created or one of the example input files must be used. Steps for creating and editing input files will be described below.

EDIT/CREATE INPUT DATA

General

The Edit/Create feature allows the user to either make changes to (edit) an existing input data file or to create a new input data file. After selecting "*Edit/Create Input Data*" from the Module Menu, the following form will appear.

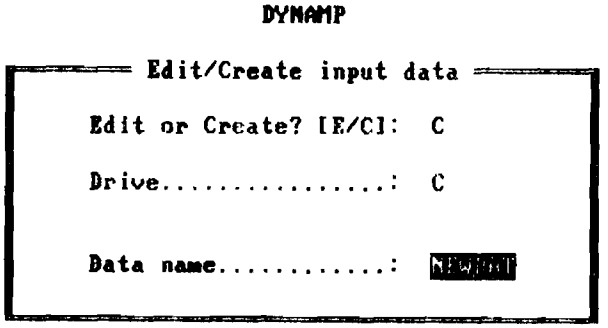


e user is now presented with three prompts. The first prompt asks the user to ter an "E" or "C". The user may choose to edit an existing input data file by tering "E", or the user may choose to create a new input data file by entering '. After entering either "E" or "C" the user is asked to select the letter 'responding to the computer drive unit. The user is then asked to specify the ıe of the data file that is to be edited or created. Note that at any time the r may press [F1] for help or press the [Esc] key to return to the Module Menu.

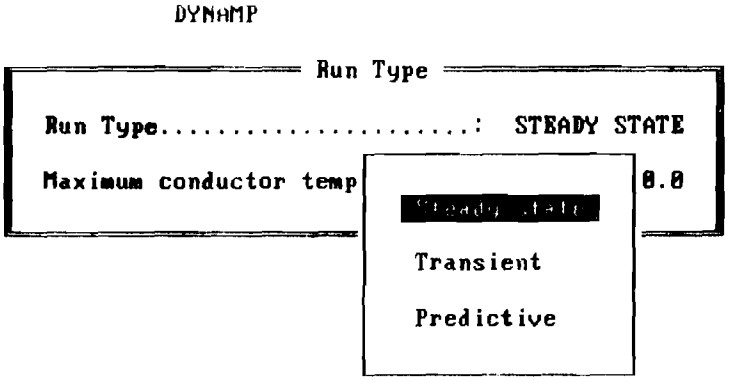
Creating an Input File

If the user chooses to create an input file, the drive letter and the name of the new input file must be specified. Any name that is not already assigned to a file can be used. After entering the file name, the user will be allowed to create input data by responding to a sequence of prompts and menus.

For example, suppose it is desired to create a steady-state file called "NEWDAT"

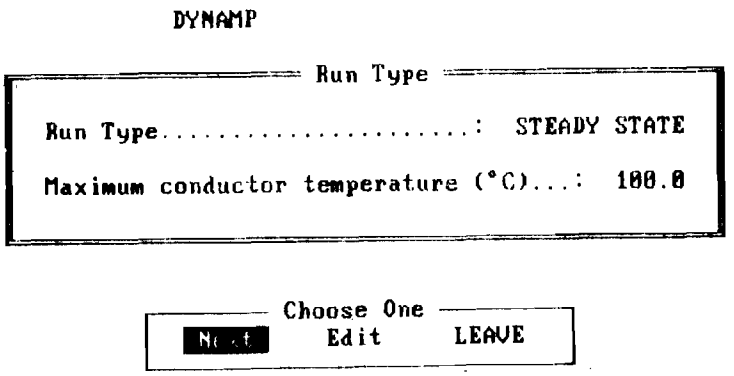


After entering the name NEWDAT, the following menu will appear to prompt for the run type options.



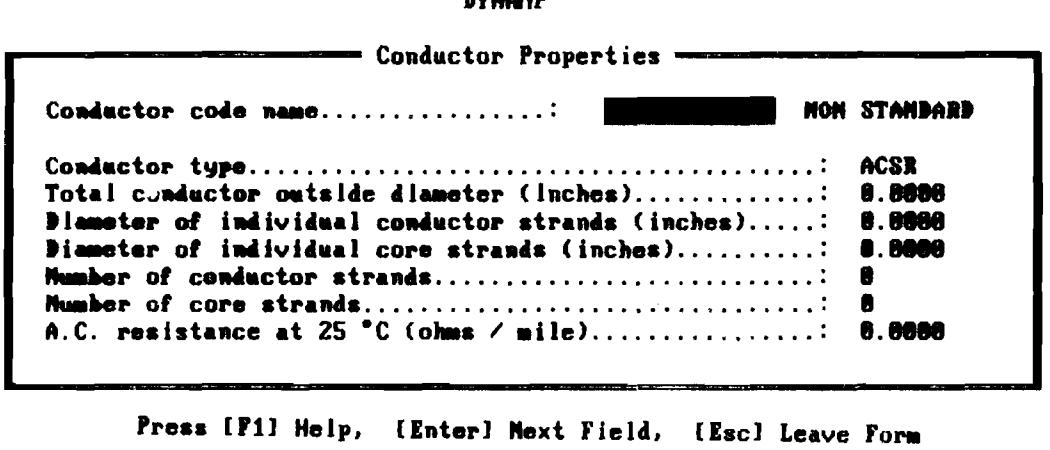
If the user is not sure of the definitions of the selections, the [F1] key can be pressed for help. Since it is desired to run the program for steady-state

conditions, the default selection *"Steady-State"* is selected. After pressing the [Enter] key, the following display appears.



If the user desires to edit the run type option again, *"Edit"* is selected. If the user desires to move to the next data group, then *"Next"* is selected. If the user desires to leave the create file session without saving the new file, *"LEAVE"* is selected and program control returns to the Module Menu.

If *"Next"* is selected, the following prompts for the Conductor Properties data set appear.


DYNAMP
Conductor Properties
Conductor code name.....: NON STANDARD
Conductor type.....: ACSR
Total conductor outside diameter (inches).....: 0.0000
Diameter of individual conductor strands (inches).....: 0.0000
Diameter of individual core strands (inches).....: 0.0000
Number of conductor strands.....: 0
Number of core strands.....: 0
A.C. resistance at 25 °C (ohms / mile).....: 0.0000
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

In response to this form, the user may enter the code name of the desired conductor and the conductor properties will be automatically entered. If the user wishes to enter properties for a non-standard conductor, then those properties

must be entered manually. Assuming for this example case it is desired to use a CURLEW conductor, the following form will appear after *"CURLEW"* is entered in response to the conductor code name prompt.

DYNAMP

Conductor Properties

Conductor code name.....:	**CURLEW**
Conductor type.....:	**ACSR**
Total conductor outside diameter (inches).....:	**1.2450**
Diameter of individual conductor strands (inches).....:	**0.1383**
Diameter of individual core strands (inches).....:	**0.1383**
Number of conductor strands.....:	**54**
Number of core strands.....:	**7**
A.C. resistance at 25 °C (ohms / mile).....:	**0.0910**

Select One

Edit **LEAVE**

As in the case for the run type option, the user selects *"Next"* to go to the next data group. To continue editing the Conductor Properties, *"Edit"* is selected. If the user wishes to terminate the created file session, *"LEAVE"* is selected.

After selecting *"NEXT"*, the form for Date and Time input data set will appear.

DYNAMP

Date & Time

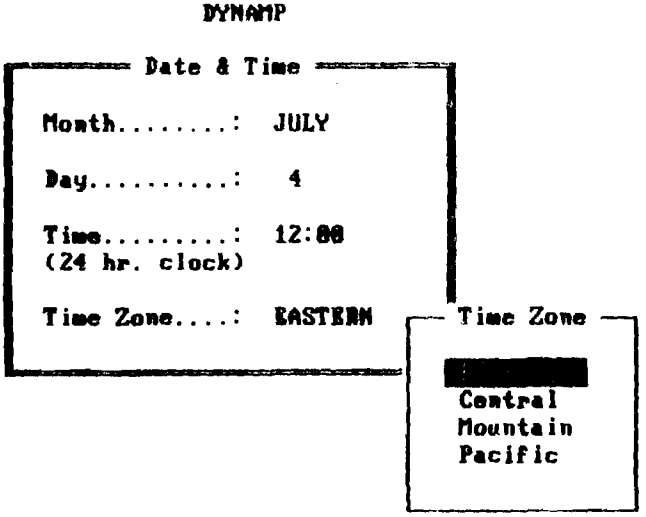
Month.....:	**JULY**
Day.....:	**4**
Time.....: **(24 hr. clock)**	**12:00**
Time Zone....:	**EASTERN**

Month

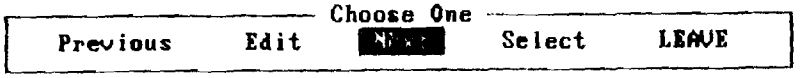
January
February
March
April
May
June
July
August
September
October
November
December

Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

This form allows the user to select the month from a menu. Once the user has selected the month, he is expected to enter the day and time based on a 24 hour clock. To complete the Date and Time information, a menu will appear requesting the user select one of the four time zones in the continental United States. The screen image requesting time zone information is shown in the figure below.



ter the Date and Time variables have been entered, the user must respond to the nu shown below



order to go to the next data group, to edit date and time variables, or to minate the session.

er selecting "NEXT" to proceed to the next variable group, the user will see following screen image which prompts for the Line Location data set.

DYNAMP

Line Location

Latitude (Degrees North).....	[redacted]
Longitude (Degrees East).....	182.8
Conductor inclination angle (degrees).....	8.8
Conductor axis azimuth (degrees).....	8.8
Elevation above sea level (feet).....	8

Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The user should respond to these five prompts by entering the desired values for Latitude, Longitude, Conductor inclination angle, Conductor axis azimuth, and Elevation above sea level. If the user is unsure of the definitions of these variables, the [F1] key should be pressed. After the desired values are entered, the user should respond to the menu,

Choose One

Previous Edit [redacted] Select LEAVE

by selecting "NEXT".

The next data set to be entered is Radiation Properties and the prompts shown below will appear on the screen.

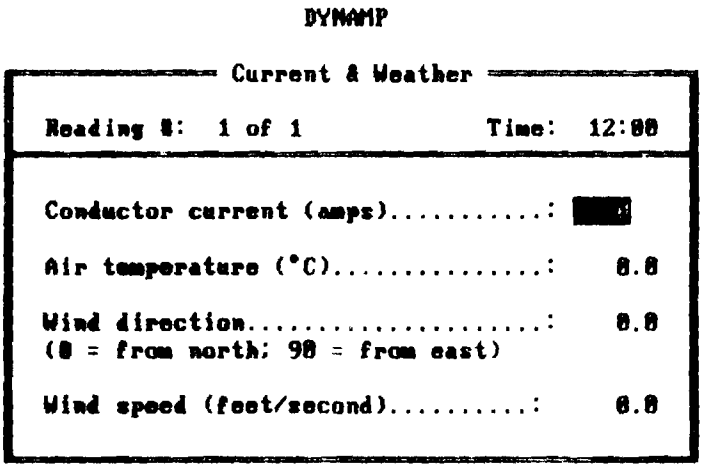
DYNAMP

Radiation Properties

Solar Absorptivity.....	[redacted]
Conductor Emissivity.....	0.60

Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The next data set to appear will be the Current and Weather variables as illustrated in the screen image shown below.


DYNAMP
Current & Weather
Reading #: 1 of 1
Time: 12:00
Conductor current (amps).....:
Air temperature (°C).....: 0.0
Wind direction.....: 0.0
(0 = from north; 90 = from east)
Wind speed (feet/second).....: 0.0
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

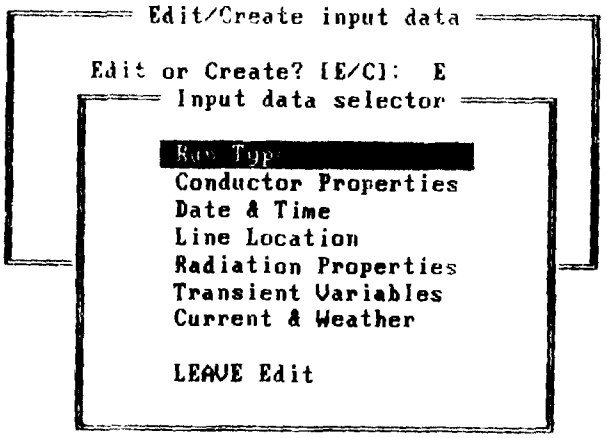
ere, the user must respond by entering the desired conductor current (amps) and ie weather conditions. The weather conditions include the ambient temperature eg C) wind direction (degrees), and the wind speed (feet/second).

ter the current and weather data have been entered, the user will have entered l of the necessary information needed for this example which is a steady-state out file. However, if it is desired to further edit the contents of the file fore saving it, the user will be given a chance to do so. If no further editing desired, the program will save the newly created file (in this example the file led "*NEWDAT*") and return the user to the Module Menu.

ting Input Data Files

General If the user has chosen to edit an existing data file, the following will appear after the data file name has been entered.

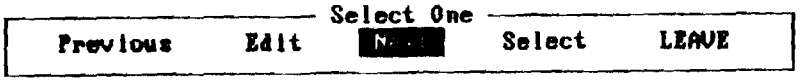
DYNAMP



Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

his menu, referred to as the "*Input Data Selector*", allows the user to select any ne of the data groups listed on the screen. Each data group exists on a separate page" of input, and any one of the pages may be selected for editing. In the reen image shown above, the highlighted block is positioned over the "*Run Type*" ge.

ter the user has selected a page of data to edit, more menus and prompts will pear allowing the user to modify data on that page of input. The user should swer the menus by selecting a choice with the space bar and then pressing the nter] key. Prompts should be answered by entering the desired values in the elds following the questions. After a page of input data has been edited and of the prompts have been answered, the following menu will appear at the tom of the screen.



s menu allows the user to perform one of five possible tasks.

. If the user wishes to edit data on the page that exists prior to the present page of data, "*Previous*" should be selected from the menu.

2. If the user wishes to continue editing the present page of data, *"Edit"* should be selected.

3. If the user wishes to edit data on the page immediately following the present page, *"NEXT"* should be selected.

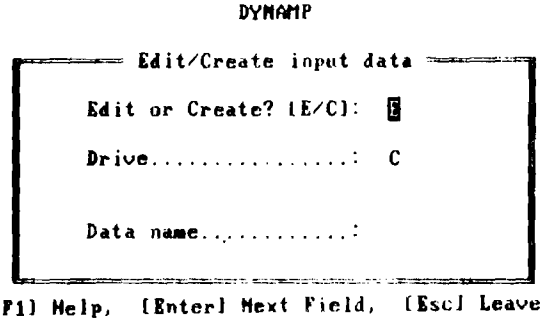
4. If the user desires to return to the Input Data Selector, *"Select"* should be used.

5. If the user has completed all editing of the input data file, *"LEAVE"* should be selected.

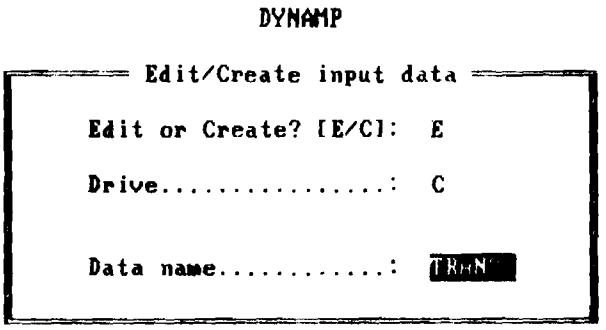
The editing of each page of data is relatively simple. However, two of the data groups presented in the Input Data Selector, *"Conductor Properties"* and *"Current and Weather"*, may give some difficulty to the first-time user. To reduce any potential difficulties, an explanation of the editing procedure of these two data groups is given below.

Editing Current and Weather Data DYNAMP must be given the conductor current and weather conditions in order to make temperature calculations. If the steady-state mode is selected, only one set of current and weather data is needed; that is, only one value of steady-state conductor current, ambient temperature, wind direction, and wind speed is needed. However, if the transient or predictive modes are selected, several sets of current and weather data are required. Each set corresponds to a particular time and date and each set is separated from adjacent sets by a time equal the value for Time Interval specified in the Transient Variables menu.

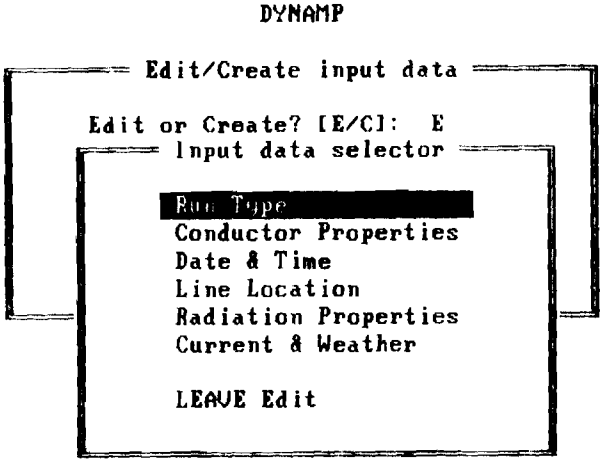
As an example, suppose it is desired to change current and weather data in a file called *"TRANS"*. After selecting *"Edit/Create Input Data"* from the Module Menu, the following prompts appear.



The user should respond by typing an "E" for edit in the first prompt. Assuming the data files are stored on drive C, the user enters "C" in response to the second prompt. Since the file name is called TRANS, the user enters "*TRANS*" in response to the third prompt as shown below.

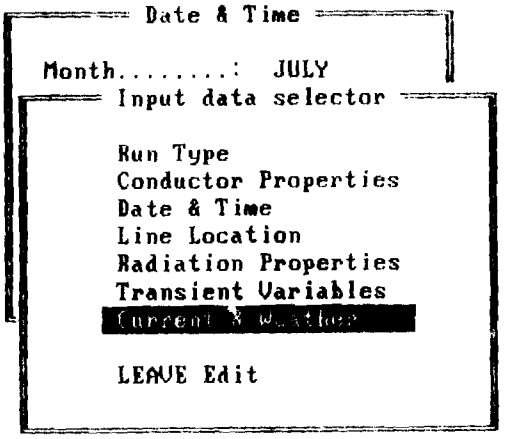


After the file name is entered, the Input Data Selector Menu appears.



ince current and weather data are to be edited, the user selects the "*Current* *d Weather*" page by pressing [Enter] when the appropriate title is highlighted. e following series of prompts then appears

DYNAMP

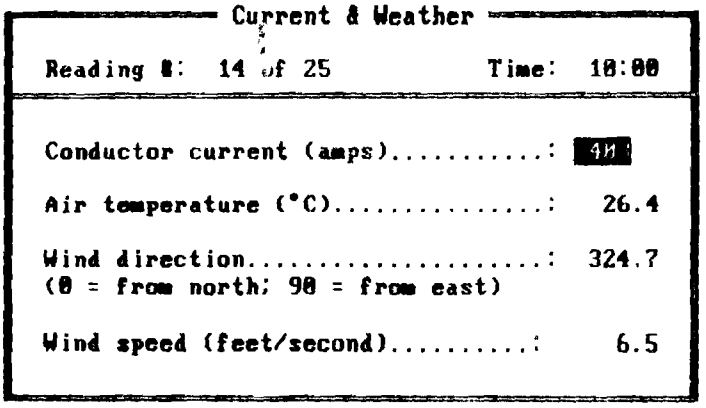


Which set of "Current & Weather Conditions"? (1 thru 25) 14

Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

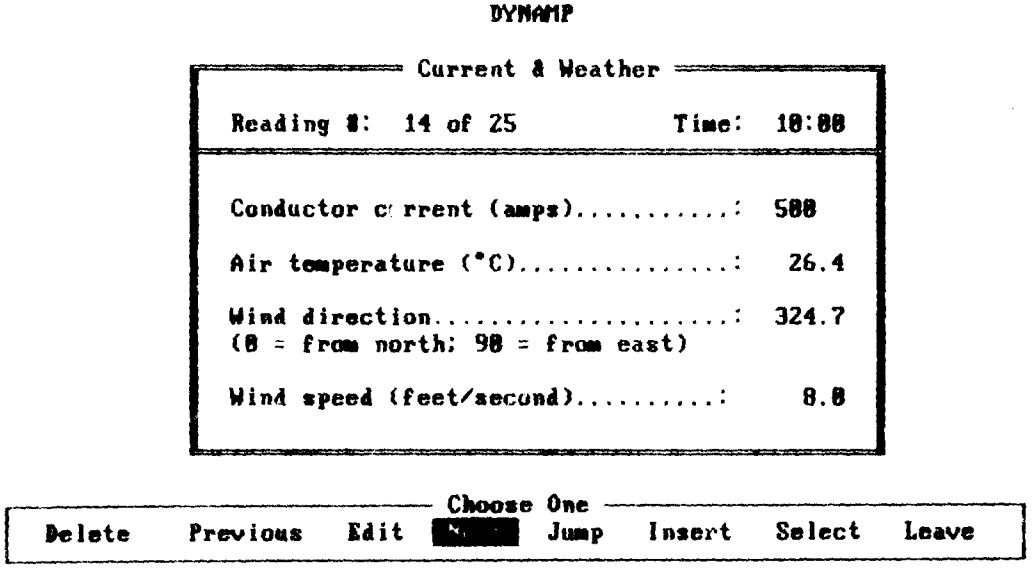
The user must respond by entering a number between 1 and the total number of sets (25 in this example) of current and weather data. In this example assume the user wishes to modify data in set number 14. Thus the user responds to the prompt by entering "14". After a moment, the current and weather data for set number 14 appears on the screen as

DYNAMP


Current & Weather
Reading #: 14 of 25
Time: 10:00
Conductor current (amps).....: 400
Air temperature (°C).....: 26.4
Wind direction.....: 324.7
(0 = from north; 90 = from east)
Wind speed (feet/second).....: 6.5

Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The user is now given the opportunity to modify any of the displayed data. Suppose, for example, it is desired to change the current from 403 amps to 500 amps. The user also wishes to change the wind speed from 6.5 feet/second to 8.0 feet/second. The user simply enters the correct values for those two fields. The air temperature and wind direction fields will remain unchanged if the [Enter] key is pressed without making changes to those fields. After the new value for wind speed has been entered, the following form is displayed.



The menu on the bottom of the screen gives the user eight options.

1. *"Delete"* is selected to delete the set of data displayed on the screen.

2. *"Previous"* is selected to edit the current and weather data set that is on the previous line to the current and weather data set displayed on the screen (in this example line number 13).

3. *"Edit"* is selected to edit the current and weather data set displayed on the screen.

4. *"Next"* is selected to edit the current and weather data set on the following line to the one displayed on the screen (in this example line number 15).

5. "*Jump*" is selected to allow the user to jump over to a set of Current and Weather Data not adjacent to the one displayed.

6. "*Insert*" is selected to insert a new data either before or after the data set displayed.

7. "*Select*" is used to return the user to the Input Page Menu.

8. "*Leave*" is selected to close the editing session.

In the present example, assume the user wishes to modify current and weather data on line number 20. The user should then select "*Jump*". The user will then be asked to enter the data line number through a prompt appearing on the screen image shown below.

DYNAMP

Current & Weather

Reading #: 14 of 25 Time: 10:00

Conductor current (amps).....: 500

Air temperature (°C).....: 26.4

Wind direction.....: 324.7
(0 = from north; 90 = from east)

Wind speed (feet/second).....: 8.0

are 25 sets of "Current and Ambient Conditions"
set to jump to: [redacted]

Choose One

lete Previous Edit Next [redacted] **Insert Select Leave**

entering "20" in response to the prompt as shown above, the current and er data for data line number 20 will appear on the screen.

DYNAMP

Current & Weather

Reading #: 20 of 25 Time: 18:00

Conductor current (amps).....: 399

Air temperature (°C).....: 27.5

Wind direction.....: 316.7
(0 = from north; 90 = from east)

Wind speed (feet/second).....: 11.0

Choose One

Delete Previous Edit Next Jump Insert Select Leave

The user can now modify current and weather data on line 20. After modifying the current and weather data for this set, the user will again be given the eight options

Choose One

Delete Previous Edit Next Jump Insert Select Leave

displayed at the bottom of the screen.

This process will continue until the user is satisfied with the modifications to the input data file. When all desired modifications have been made, the user would select "Leave", from the eight options shown above or from the Input Page menu. After selecting "Leave", the user will be prompted for the name of the file which the modified data is to be written.

DYNAMP

Write modified data set

Drive....: A

Data name: TRANS

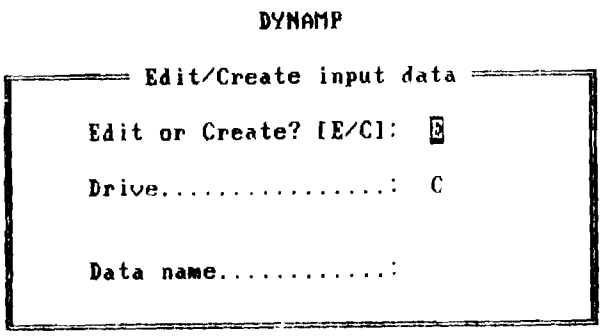
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

If the user chooses to keep the same file name (in this example *"TRANS"*) then any previous output file called *"TRANS"* will be deleted. However, if the user chooses a different name for the new input file, then no output will be deleted.

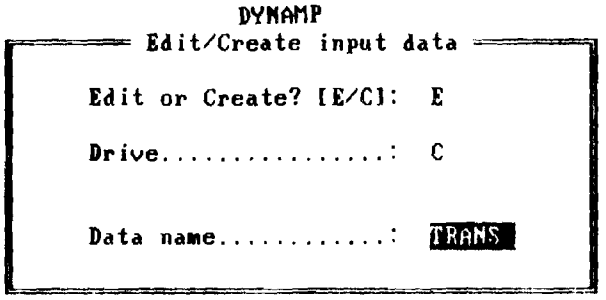
After entering the name of the input file, the Module Menu will return to the screen.

Editing Conductor Properties. Editing conductor properties can be accomplished by specifying the code name of the conductor (such as DRAKE or VIOLET) or by manually entering the desired conductor diameter, number of conductor strands, etc.

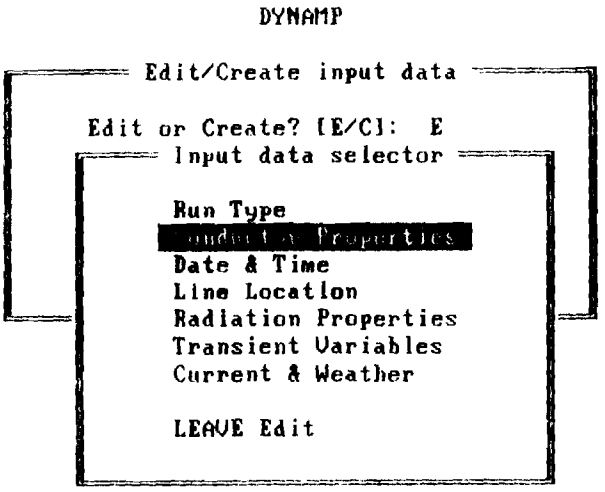
As an example, suppose it is desired to change the conductor properties in the input file *"TRANS"* to those for a CURLEW conductor. After selecting *"Edit/Create Input Data"* from the Module Menu, the user will receive the following prompt.



Since it is desired to edit the file TRANS, the user should respond to the prompts as follows:

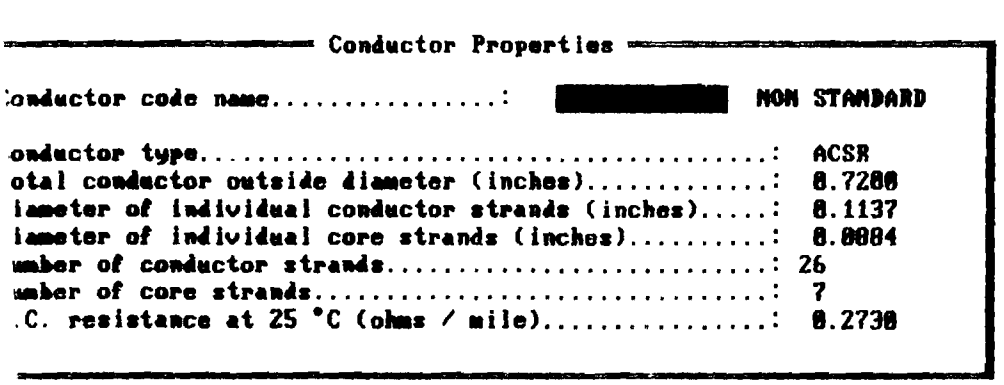


After entering the name of the input data file, the user will receive the Input Data Selector Menu.



The user should respond to this menu by selecting *"Conductor Properties"* since it is desired to edit those properties.

After making that selection, the following form will appear.


DYNAMP
Conductor Properties
Conductor code name.....: NON STANDARD
Conductor type.....: ACSR
Total conductor outside diameter (inches).....: 0.7200
Diameter of individual conductor strands (inches).....: 0.1137
Diameter of individual core strands (inches).....: 0.0884
Number of conductor strands.....: 26
Number of core strands.....: 7
D.C. resistance at 25 °C (ohms / mile).....: 0.2730
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

This form gives the conductor properties for the present conductor in the input data file TRANS. To change these properties to those for a CURLEW conductor, the user enters *"CURLEW"* in the field following the prompt for the conductor code name. After entering *"CURLEW"*, the program automatically changes the properties to those for a CURLEW conductor and the following screen image appears.

DYNAMP

Conductor Properties

Conductor code name.....:	**CURLEW**
Conductor type.....:	**ACSR**
Total conductor outside diameter (inches).....:	**1.2450**
Diameter of individual conductor strands (inches).....:	**0.1303**
Diameter of individual core strands (inches).....:	**0.1303**
Number of conductor strands.....:	**54**
Number of core strands.....:	**7**
A.C. resistance at 25 °C (ohms / mile).....:	**0.0910**

Select One

Previous **Edit** [redacted] **Select** **LEAVE**

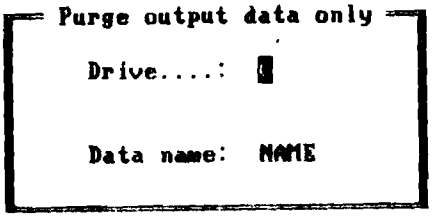
f the user desires to manually enter the conductor properties, the [Enter] key is ressed in response to the code name prompt, and the highlighted block will oceed to the field of *"Conductor Type"*.

ter the modifications are made to the file, the user should select *"LEAVE"* to ose the edit session. At this time, the user will be prompted for the new input le name as shown earlier in the current and weather example. After the new file me is specified, the Module Menu will return to the screen.

'GE OUTPUT DATA ONLY

purge output data, the user should select *"Purge Output Data Only"* from the ule Menu. The following prompts will appear.

DYNAMP



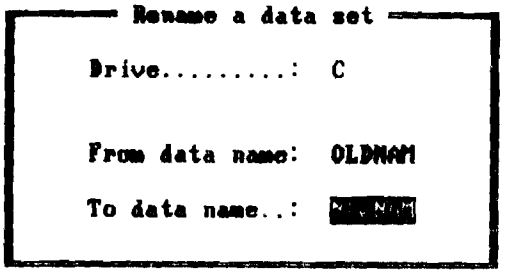
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The use should respond by entering the drive letter and the name of the output file to be purged.

RENAME A DATA SET

To rename a set of data, the user should select *"Rename a Data Set"* from the Module Menu. The following prompts will appear.

DYNAMP



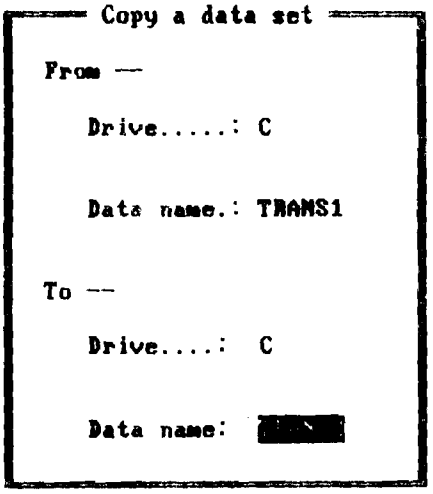
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The user should enter the drive letter in response to the first prompt. The prompt *"From Data Name:"* asks for the present name of the data set. The prompt *"Data Name:"* asks for the new name of the data set. After the prompts are answered the Module Menu will return.

COPY A DATA SET

If the user wishes to copy a data set from one file to another, *"Copy a Data Set"* should be selected from the Module Menu. The following prompts will appear.

DYNAMP



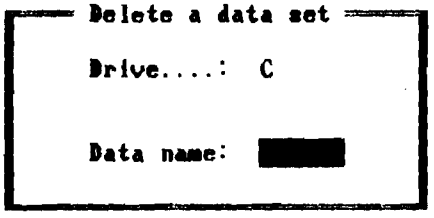
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

he first prompt asks the user to enter the name of the data set that is to be
:pied. The user then enters the name of a second file to which the contents of
he first data set is to be copied.

LETE A DATA SET

the user wishes to erase a complete data set, *"Delete a Data Set"* is selected
om the Module Menu. The following prompts will appear.

DYNAMP



Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

user should respond by entering the drive letter and the name of the data set
is to be deleted.

DIRECTORY LISTING

Directory listing allows the user to review the names of all raw input data files, documented input data files, and output data files. After selecting *"Directory Listing"* from the Module Menu, the following prompt will appear.

DYNAMP

Directory Listing

Drive: C

Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The user should respond by entering the drive letter in which the files are located. After entering the drive letter, the directory listing will appear which will be similar to the following listing.

DYNAMP

Directory Listing

Raw Input

PREDCT STEADY TRANS VITO NEWDAT

Documentation of Input (A Report Option)

***** NONE FOUND *****

Output

VITO

End-of-report

Esc]-Leave, [PgUp]-Prev, [PgDn]-Next, [Home]-Top, [End]-Bottom, ◄ ► ▲ ▼ *END*

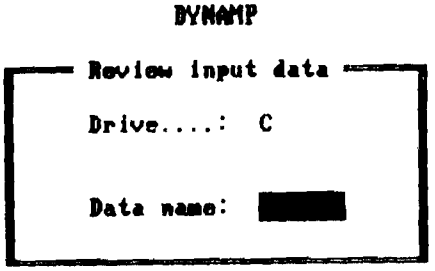
The data files will be listed in one of three categories:

Raw Input
Documented Input
Output

If the listing occupies more than one screen, the [PgDn], [PgUp], [Home], and [End] keys can be used to move through the listing. To return to the Module Menu, press the [Esc] key.

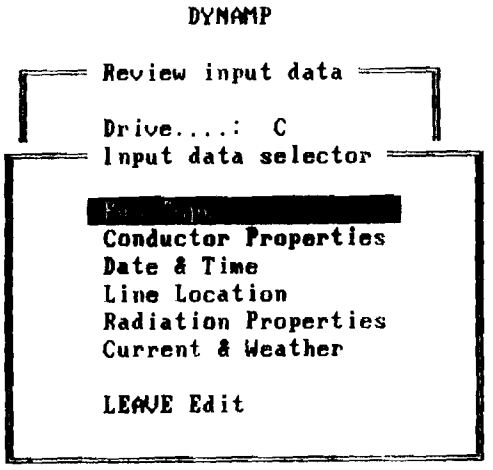
REVIEW INPUT DATA

Occasionally it is desirable to review input data files before executing the program. This procedure can be accomplished by selecting *"Review Input Data"* from the Module Menu. After making this selection the following prompt will appear on the screen.



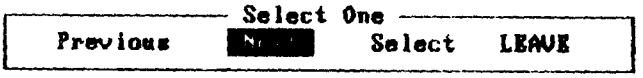
Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

The user should respond by entering the drive letter and the name of the input data file that is to be reviewed. After responding to the prompts, the following menu will appear on the screen.



Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

This menu allows the user to select the data group (input page) that is to be reviewed. After that selection is made, the input page will be displayed with the following menu located at the bottom of the screen.

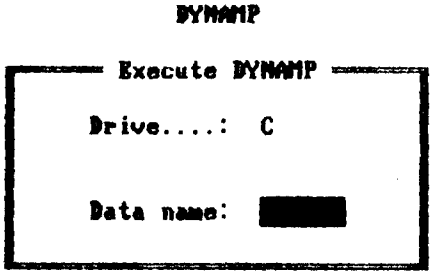


If the user desires to go to the previous input page, *"Previous"* should be selected. *"Next"* is selected, if it is desired to go to the next input page. To return to the Input Page Menu, use *"Select"*. To return to the Module Menu, select *"Leave"*.

EXECUTE DYNAMP

When the user wishes to execute the DYNAMP program, *"Execute DYNAMP"* is selected from the Module Menu. This procedure will produce an output file with the same name as the raw input file. As stated earlier, the two files are referred to as a data set, and this data set will have the same name as the input and output files.

After selecting *"Execute DYNAMP"*, the user will be asked to enter the raw input data file name with the following prompt.



Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

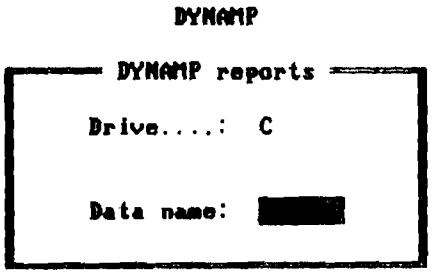
n the user has entered the name of the raw input data file, the DYNAMP program be automatically executed. After execution, the newly created output file be stored with the same name as the raw input data file. However, the two s will continue to exist separately. After the file is stored, the output be printed to the screen for review by the user. To return to the Module , the user should press the [Esc] key.

DYNAMP REPORTS

DYNAMP reports enables the user to print a formatted input file or output file. These files may be written to a printer or to the computer screen.

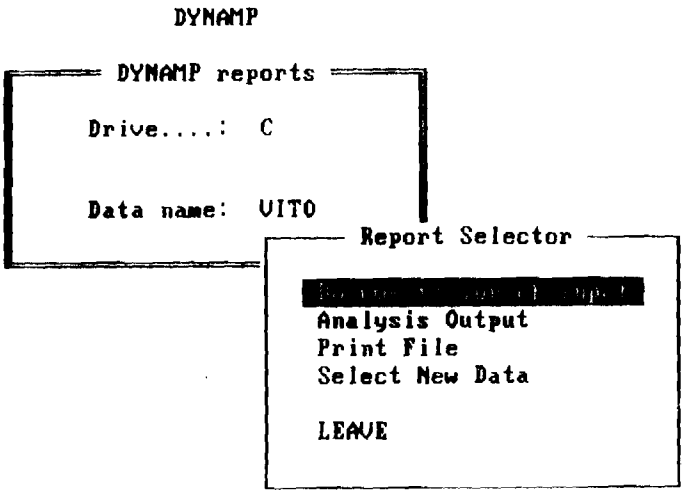
In addition, DYNAMP reports will allow the user to incorporate several different files into one large file. This file, called a print file can then be written to the screen or printer.

After selecting *"DYNAMP Reports"* from Module Menu, the user is prompted for the drive letter and data file name as shown in the screen image below.



Press [F1] Help, [Enter] Next Field, [Esc] Leave Form

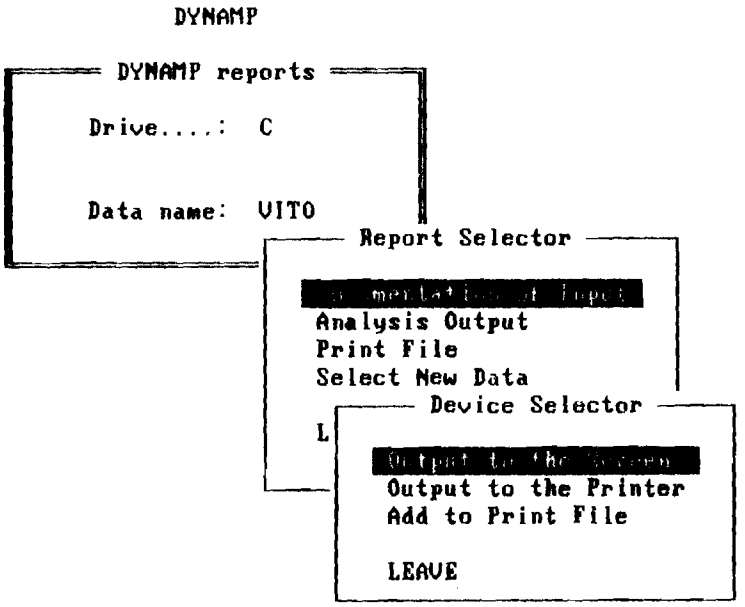
This file name will include the formatted input file as well as the output file. After the user has entered the file name, the following menu will appear on the screen.



Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

The Report Selector Menu allows the user to select either the documented input file corresponding to the file name just entered or the output file (*"Analysis Output"*) corresponding to the file name just entered. If the user wishes to have a documented input file and no documented input file exists, then a documented input file will be created for the user. In addition, the user can select a print file or a new data set name *"Select New Data"*.

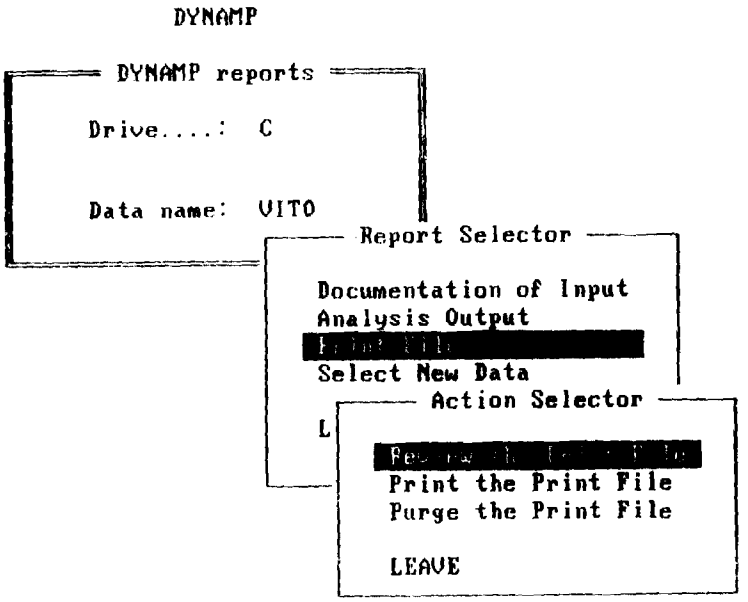
If either *"Documentation of Input"* or *"Analysis Output"* is selected, the Device Selector Menu will appear on the screen superimposed over the Report Selector Menu.



ess [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

is menu allows the user to select the printing destination of the file (either ie Documented Input or Output file). If it is desired to print the file to the reen, then *"Output to the Screen"* is selected. If the file is to be routed to a inter the *"Output to the Printer"* is selected. Finally, the file can also be ded to the print file, which can be sent to the printer at a later time.

"Print File" is selected from the Report Selector Menu, the Action Selector u will appear as shown below.



Press [F1] Help, [Space Bar] Next Choice, [Enter] Select Choice

This menu will allow the user to perform three tasks. First, the user may review the print file on the screen by selecting *"Review the Print File"*. Second, the user may send the print file to the printer by selecting *"Print the Print File"*. Third, the user can select *"Purge the Print File"* to completely erase the Print File.

If *"Select New Data"* is selected from the Report Selector, then the user will be prompted for the name of another data set.

If at any time, the user wishes to leave a menu to return to a previous menu, then *"Leave"* should be selected from the last menu appearing on the screen.

DYNAMP HELP FACILITY

When this facility is selected, a condensed users guide will be printed to the screen. Most general questions may be answered through this facility.

LEAVE DYNAMP

When the user completes calculations with DYNAMP and wishes to return control to the TLWorkstation Master Menu, the *"Leave DYNAMP"* command should be selected from the Module Menu.

Section 4

EXAMPLE PROBLEMS

This section illustrates the use of DYNAMP with three typical examples: a steady-state, a transient and a predictive case. Each example includes a documented input file and the corresponding output file obtained by executing DYNAMP.

STEADY-STATE OPTION

To illustrate the steady-state option, consider the following example. Calculate the temperature of a Linnet ACSR conductor (26/7, 336.4 kcmils) for a current of 350 amps and the ampacity for a temperature of 100°C. Perform the calculation for the Atlanta area on June 3rd at 9:04 A.M. The conductor is horizontal and oriented in a north-south direction. The solar absorptivity and infrared emissivity of the conductor surface are 0.50 and 0.30 respectively. The ambient air temperature is 25°C and the wind is from the west at 2.0 ft/sec.

To assemble an input file for this particular problem, the user can proceed through each input page and respond to the various prompts. To simplify input of conductor properties, the user can specify the conductor code name (LINNET for this case) and the program will automatically select the correct conductor properties. The latitude and longitude for Atlanta are 34.2° and 84.1°, respectively (see Figure 2-1) and the mean altitude above sea level for Atlanta is approximately 1000 feet. The inclination of the conductor is zero (horizontal) and the conductor azimuth is also zero (North-South orientation). The documented input file for this particular example is shown in Figure 4-1.

The output file provided by DYNAMP for this example is shown in Figure 4-2. The program first calculates the mass and cross-sectional area for both the conductor and core strands. It also calculates the skin effect of the composite conductor using the input value for A.C. resistance and a calculated value for the D.C. resistance. The final line of output contains the time for which the ampacity and temperature calculations are carried out, the conductor current and the weather conditions. Also on this line of output is the calculated conductor temperature (93.9°C for this example) which exists for the given current and weather conditions. The final calculated value on this line of output is the 100°C ampacity value which is 596 amps for the given conditions.

```
                                D Y N A M P

                DYNamic AMpacity PROGRAM  **  Version 1.20

        Developed by Georgia Institute of Technology and Georgia Power Company

                                Under EPRI RP2546-1

        INPUT DATA, STEADY STATE CALCULATIONS for LINNET Conductor

 Conductor Properties
 ---------- ---------- ----------------------------------------
 CODE ID:  ACSR   ALUM 1350 COND, STEEL CORE
 TOTAL OUTSIDE DIAMETER                  0.7200  INCHES
 CONDUCTOR STRAND DIAMETER               0.1137  INCHES
 CORE STRAND DIAMETER                    0.0884  INCHES
 NUMBER OF CONDUCTOR STRANDS             26
 NUMBER OF CORE STRANDS                  7
 D.C. RESISTANCE (25 DEG C)              0.2730  OHMS/MILE


 Line Location Variables
 ---- -------- ---------- ----------------------------------------
 DATE AND TIME                    6/03   9:04  EASTERN
 LATITUDE                                34.2  DEG
 AZIMUTH                                 84.1  DEG
 CONDUCTOR INCLINATION                    0.0  DEG
 CONDUCTOR AZIMUTH                        0.0  DEG
 ELEVATION ABOVE SEA LEVEL             1000.    FT


 Material Properties
 -------- ---------- ----------------------------------------
 SOLAR ABSORPTIVITY                      0.50
 EMISSIVITY                              0.30


 Weather Variables
 ------- ---------

 CRITICAL TEMPERATURE IS 100 DEG C

                  AIR     WIND  WIND
 CASE    SCNE     TEMP    DIR   SPEED
 ----    ----     ----    ---   -----
                  DEG C   DEG    FT/S
                  -----   ---    ----
   1      TE      25.0     90    0.6
```

Figure 4-1. Documented Input File for Steady-State Example.

D Y N A M P

DYNamic AMPacity PROGRAM ** Version 1.20

Developed by Georgia Institute of Technology and Georgia Power Company

Under EPRI RP2546-1

INPUT DATA, STEADY STATE CALCULATIONS for LINNET Conductor

Conductor Properties

TYPE IS: ACSR - ALUM 1350 COND, STEEL CORE		
TOTAL OUTSIDE DIAMETER	0.7200	INCHES
CONDUCTOR STRAND DIAMETER	0.1137	INCHES
CORE STRAND DIAMETER	0.0884	INCHES
NUMBER OF CONDUCTOR STRANDS	26	
NUMBER OF CORE STRANDS	7	
A.C. RESISTANCE (25 DEG C)	0.2730	OHMS/MILE

Line Location Variables

DATE AND TIME	6/03	9:04	EASTERN
LATITUDE		34.2	DEG
LONGITUDE		84.1	DEG
CONDUCTOR INCLINATION		0.0	DEG
CONDUCTOR AZIMUTH		0.0	DEG
ELEVATION ABOVE SEA LEVEL		1000.	FT

Radiation Properties

SOLAR ABSORPTIVITY	0.50
EMISSIVITY	0.30

Figure 4-2. Output File for Steady-State Example.

D Y N A M

DiNamic AMPacity PROGRAM ** Version 1.20

Developed by Georgia Institute of Technology and Georgia Power Company

Under EPRI RP2546-1

OUTPUT DATA. STEADY STATE CALCULATIONS for LINNET Conductor

Calculated Values

CONDUCTOR MASS	0.3171 LBS/FT
CORE MASS	0.1455 LBS/FT
CONDUCTOR AREA	0.2640 SQ. IN.
CORE AREA	0.0430 SQ. IN.
SKIN EFFECT	1.0022

Steady State Calculations

DATA TYPE	COND AMPS	AIR TEMP DEG C	WIND DIR DEG	WIND SPEED FT/S	COND TEMP DEG C	AMPS FOR 100 DEG C
DATA	750	25.0	90	2.0	53.9	596

Figure 4-2. Output File for Steady-State Example. (Continued)

TRANSIENT OPTION

The example to illustrate the use of the program for transient or real-time temperature calculations is identical to the one in the previous section except that the calculations are made for varying currents and weather conditions. Using the same conditions as stated in the previous example for steady-state calculations, calculate the temperature of a Linnet conductor for currents ranging between 350 and 410 amps, for air temperatures between 15 and 25°C, for wind directions between 0 and 90° to the conductor axis and for wind speeds between 1 and 10 ft/sec. All current and weather data are separated by 5 minute intervals and the conductor temperatures are to be calculated on 5 minute intervals.

The documented input file for this example is shown in Figure 4-3. The input values for all data with the exception of the Transient Variables and the Current and Weather data are identical to the values used in the previous example. The Transient Variables are new for this example and they are 5 minutes for both the current and weather time interval and the print time interval. The weather and current data are listed at the bottom of the file. To make the weather and current array a reasonable length, only a few representative values which range over the desired values were selected. The wind speed is varied from 1 to 10 ft/sec for the first 5 data sets (20 minute time interval) and it is then held constant for the remainder of the data set. The next variable that is changed is the current which is increased from 350 to 410 amps while all other conditions remain unchanged. At 10:14 A.M. the wind changes from perpendicular flow to axial flow and it remains at zero degrees for the remainder of the data set. At 10:49 A.M. the air temperature decreases from 25°C to 15°C.

The output corresponding to the input file in Figure 4-3 is shown in Figure 4-4. The first portion of the output file is identical to the steady-state output with the calculations consisting of mass and cross-sectional for both the conducting and supporting strands and the skin effect. The last lines of the output file show the time, current, weather conditions along with the calculated conductor temperature. The trend in the conductor temperatures as a function of time shows the expected results considering the input values for current and weather conditions. The temperature first decreases dramatically as a result of the increase in wind velocity. At 9:44 A.M. the temperature begins to increase, because of the increase in conductor current. At 10:14 A.M. the temperature increases further, because at that time the wind direction changes to blow down the axis of the conductor. And finally, the conductor temperature drops starting at 10:49 A.M. when the ambient air temperature decreases by 10°C.

```
                                    D Y N A M E

                    ** AMPacity PROGRAM **  Version 1.20

                    Electric Power Research Institute of Technology and Georgia Power Company

                                    Under EPRI RP2546-1

                    *** Dynamic TRANSIENT CALCULATIONS for LINNET Conductor

   Conductor Properties
   --------------------------------------------------------------------------
   Conductor:  ACSR - ALUM 1350 COND, STEEL CORE
   Overall OUTSIDE DIAMETER                    0.7200   INCHES
   Conductor STRAND DIAMETER                   0.1137   INCHES
   Core STRAND DIAMETER                        0.0884   INCHES
   Number OF CONDUCTOR STRANDS                 26
   Number OF CORE STRANDS                       7
   DC RESISTANCE (25 DEG C)                    0.1730   OHMS/MILE

   Environmental Variables
   --------------------------------------------------------------------------
   Date AND TIME                      6/03     9:04   EASTERN
   WIND SPEED                                  24.2   DEG
   WIND TO LINE                                84.1   DEG
   CONDUCTOR INCLINATION                        0.0   DEG
   WIND AZIMUTH                                 0.0   DEG
   Elevation ABOVE SEA LEVEL                 1000.     FT

   Solar Properties
   --------------------------------------------------------------------------
   SOLAR ABSORPTIVITY                          0.50
   EMISSIVITY                                  0.30

   Transient Variables
   --------------------------------------------------------------------------
   CALCULATION TIME INTERVAL                   5.0   MINUTES
   PRINTOUT INTERVAL                           5.0   MINUTES
```

Figure 4-3. Documented Input File for Transient Example.

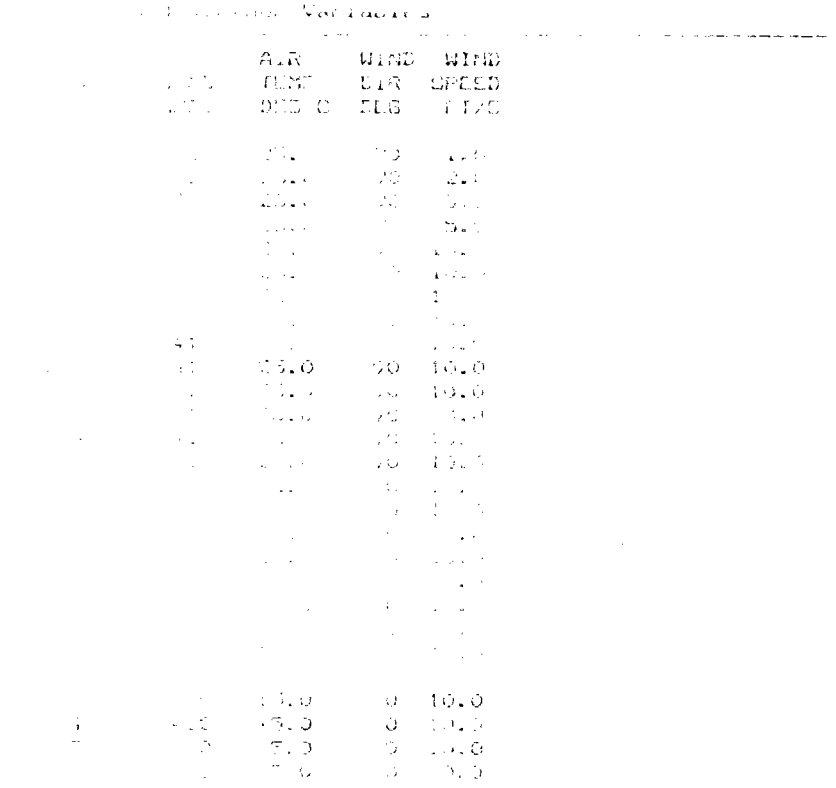


Figure 4-3. Documented Input File for Transient Example. (Continued)

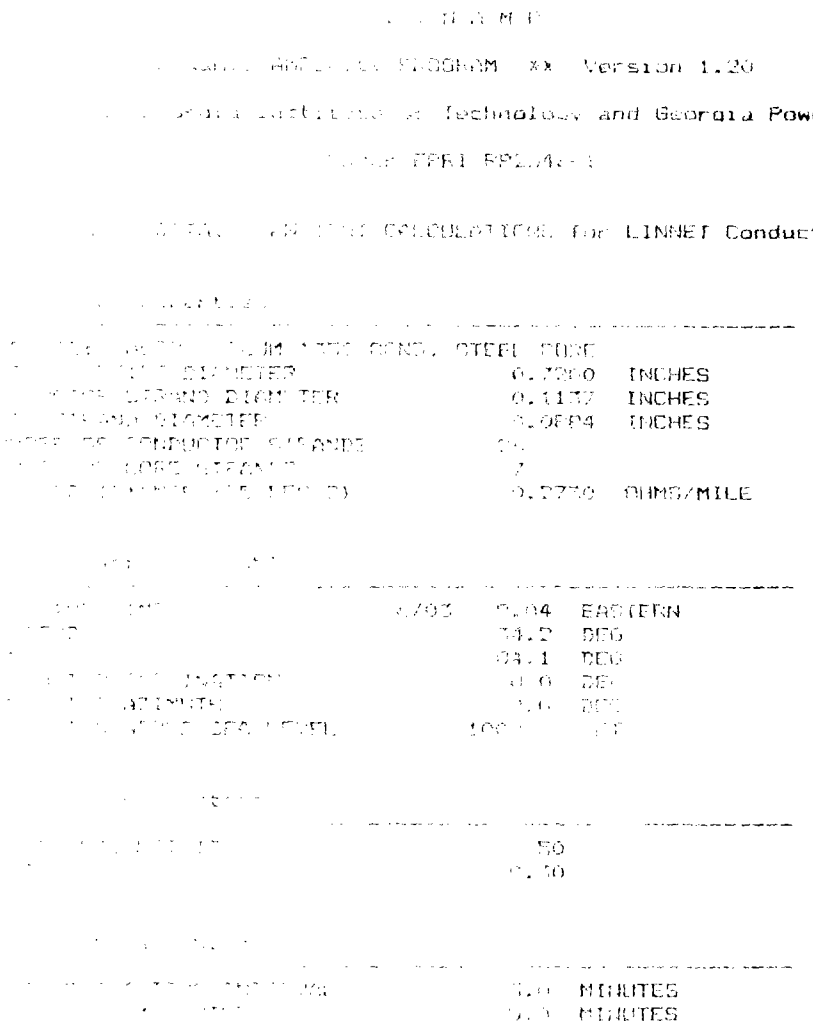


Figure 4-4. Output File for Transient Example.

[illegible] 1.20

[illegible] Georgia Power Company

[illegible] LINNET Conductor

	1.7171 LBS/FT
	1.1405 LBS/FT
	1.2640 SQ. IN.
	0.0430 SQ. IN.
	1.0022

[illegible] 6/23 9:04

	WIND DIR DEG	WIND SPEED MPH	COND TEMP DEG C
[illegible]	90	1.0	65.1
[illegible]	90	2.0	62.2
[illegible]	90	3.0	56.6
[illegible]	90	5.0	50.1
[illegible]	90	10.0	42.6
[illegible]	90	10.0	38.8
[illegible]	90	10.0	37.8
[illegible]	90	10.0	37.6
[illegible]	90	10.0	39.0
[illegible]	90	10.0	40.4
[illegible]	90	10.0	40.7
[illegible]	90	10.0	40.9
[illegible]	90	10.0	40.9
[illegible]	90	10.0	40.9
[illegible]	0	10.0	44.6
[illegible]	0	10.0	53.4
[illegible]	0	10.0	58.6
[illegible]	0	10.0	61.6
[illegible]	0	10.0	63.4
[illegible]	0	10.0	64.5
[illegible]	0	10.0	65.2
[illegible]	0	10.0	63.1
[illegible]	0	10.0	60.0
[illegible]	0	10.0	58.1
[illegible]	0	10.0	57.1
[illegible]	0	10.0	56.5
[illegible]	0	10.0	56.2

Figure 4-4. Output File for Transient Example. (Continued)

PREDICTIVE OPTION

As a final example of DYNAMP's capabilities, consider a case of using the program to predict the conductor temperature when it is subjected to a step change in current. Suppose the Linnet conductor experiences a step change in current from the values given in the previous example to a current of 750 amps. Calculate the time required for the conductor to reach an emergency limiting temperature of 100°C. All other conditions given in the previous two examples remain unchanged. The documented input file for this example is shown in Figure 4-5.

The output for this example is shown in Figure 4-6. The only addition to the input file is the value for the Predictive Variable which consists of an overload current. The last portion of the output file shows the weather conditions, conductor current and real-time temperature in a format similar to the two previous examples. However, three additional columns of data have been added to the output calculations. The last three columns list the overload current in amps, the emergency limiting temperature in °C and the elapsed time required for the conductor to increase from its present value to the value given by the emergency limiting temperature. If the elapsed time is on the order of a few seconds or minutes, the user will know that the line is near its thermal limit and its temperature will quickly reach the limiting value in a very short period of time. If the elapsed time is on the order of an hour, the line is very lightly loaded and it has a great deal of excess thermal capacity as reflected by its high value of emergency time. The program calculates an elapsed time up to two hours. If the value exceeds 120 minutes, the calculations are terminated and a value of 120 minutes is printed in the last column. In this event the conductor temperature calculated at the end of the two hour period is printed in the previous column.

The output shown in Figure 4-6 gives a brief view of typical predictive results for a Linnet conductor. The first two lines of output show the large effect that wind velocity can have on the temperature and elapsed time to reach a temperature of 100°C. When the wind velocity is 1 ft/sec and the conductor current changes from 350 to 750 amps, the conductor temperature changes from 65.1°C to 100°C in 2 minutes. When the wind velocity increases to 5 ft/sec and the conductor experiences the same change in current, the conductor temperature changes from 71°C to 100°C in an elapsed time of 8.7 minutes. The remaining lines of output also show changes in temperature and elapsed time when the air temperature, wind direction, wind velocity and current change.

```
D Y N A M P

DyNamic AMPacity PROGRAM  **  Version 1.20

Developed by Georgia Institute of Technology and Georgia Power Company

Under EPRI RP2546-1

INPUT DATA, PREDICTIVE CALCULATIONS for LINNET Conductor

Conductor Properties
--------------------------------------------------------------------
TYPE IS:  ACSR - ALUM 1350 COND, STEEL CORE
TOTAL OUTSIDE DIAMETER                    0.7300  INCHES
CONDUCTOR STRAND DIAMETER                 0.1137  INCHES
CORE STRAND DIAMETER                      0.0884  INCHES
NUMBER OF CONDUCTOR STRANDS               26
NUMBER OF CORE STRANDS                    7
D.C. RESISTANCE (25 DEG C)                0.2730  OHMS/MILE

Line Location Variables
--------------------------------------------------------------------
DATE AND TIME                  6/03   9:04  EASTERN
LATITUDE                              34.2  DEG
LONGITUDE                             84.1  DEG
CONDUCTOR INCLINATION                  0.0  DEG
CONDUCTOR AZIMUTH                      0.0  DEG
ELEVATION ABOVE SEA LEVEL           1000.    FT

Radiation Properties
--------------------------------------------------------------------
SOLAR ABSORPTIVITY                    0.50
EMISSIVITY                            0.30

Transient Variables
--------------------------------------------------------------------
MEASUREMENT TIME INTERVAL             5.0  MINUTES
PRINTING TIME INTERVAL                5.0  MINUTES

Predictive Variables
--------------------------------------------------------------------
OVERLOAD CURRENT                      750
LIMITING TEMPERATURE                  100.0  DEG C
```

Figure 4-5. Documented Input File for Predictive Example.

urrent and Weather Variables

LOCAL TIME	COND AMPS	AIR TEMP DEG C	WIND DIR DEG	WIND SPEED FT/S
7:04	350	25.0	90	1.0
7:09	350	25.0	90	2.0
7:14	350	25.0	90	3.0
7:19	350	25.0	90	5.0
9:24	350	25.0	90	10.0
9:29	350	25.0	90	10.0
9:34	350	25.0	90	10.0
9:39	350	25.0	90	10.0
9:44	410	25.0	90	10.0
9:49	410	25.0	90	10.0
9:54	410	25.0	90	10.0
9:59	410	25.0	90	10.0
10:04	410	25.0	90	10.0
10:09	410	25.0	90	10.0
10:14	410	25.0	0	10.0
10:19	410	25.0	0	10.0
10:24	410	25.0	0	10.0
10:29	410	25.0	0	10.0
10:34	410	25.0	0	10.0
10:39	410	25.0	0	10.0
10:44	410	25.0	0	10.0
10:49	410	15.0	0	10.0
10:54	410	15.0	0	10.0
10:59	410	15.0	0	10.0
11:04	410	15.0	0	10.0
11:09	410	15.0	0	10.0
11:14	410	15.0	0	10.0

Figure 4-5. Documented Input File for Predictive Example. (Continued)

D Y N A M P

DYNamic AMPacity PROGRAM ** Version 1.20

[illegible] by Georgia Institute of Technology and Georgia Power Company

Under EPRI RP2546-1

INPUT DATA, PREDICTIVE CALCULATIONS for LINNET Conductor

Conductor Properties

TYPE IS: ACSR - ALUM 1350 COND, STEEL CORE		
TOTAL OUTSIDE DIAMETER	0.7200	INCHES
CONDUCTOR STRAND DIAMETER	0.1137	INCHES
CORE STRAND DIAMETER	0.0884	INCHES
NUMBER OF CONDUCTOR STRANDS	26	
NUMBER OF CORE STRANDS	7	
A.C. RESISTANCE (25 DEG C)	0.2730	OHMS/MILE

Line Location Variables

DATE AND TIME	6/03	9:04	EASTERN
LATITUDE		34.2	DEG
LONGITUDE		84.1	DEG
CONDUCTOR INCLINATION		0.0	DEG
CONDUCTOR AZIMUTH		0.0	DEG
ELEVATION ABOVE SEA LEVEL		1000.	FT

Radiation Properties

SOLAR ABSORPTIVITY	0.50	
EMISSIVITY	0.50	

Transient Variables

MEASUREMENT TIME INTERVAL	5.0	MINUTES
SAMPLING TIME INTERVAL	5.0	MINUTES

Predictive Variables

OVERLOAD CURRENT	750	
LIMITING TEMPERATURE	100.0	DEG C

Figure 4-6. Output File for Predictive Example.

D Y N A M P

DYNamic AMPacity PROGRAM ** Version 1.20

Developed by Georgia Institute of Technology and Georgia Power Company

Under EPRI RP2346-1

OUTPUT DATA, PREDICTIVE CALCULATIONS for LINNET Conductor

Calculated Values

CONDUCTOR MASS	0.3171 LBS/FT
CAE MASS	0.1455 LBS/FT
CONDUCTOR AREA	0.2640 SQ. IN.
CORE AREA	0.0430 SQ. IN.
SKIN EFFECT	1.0022

Predictive Calculations Starting 8/03 9:04

LOCAL TIME	COND AMPS	AIR TEMP DEG C	WIND DIR DEG	WIND SPEED FT/S	COND TEMP DEG C	OVRLOAD CURRENT AMPS	OVRLOAD TEMP DEG C	ELPSD TIME MINS
9:04	350	25.0	90	1.0	65.1	750	100.0	4.2
9:09	350	25.0	90	2.0	62.2	750	100.0	5.1
9:14	350	25.0	90	3.0	56.6	750	100.0	6.5
9:19	350	25.0	90	5.0	50.1	750	100.0	8.7
9:24	350	25.0	90	10.0	42.6	750	100.0	15.8
9:29	350	25.0	90	10.0	38.8	750	97.9	120.0
9:34	350	25.0	90	10.0	37.8	750	87.5	120.0
9:39	350	25.0	90	10.0	37.6	750	80.8	120.0
9:44	410	25.0	90	10.0	39.0	750	76.4	120.0
9:49	410	25.0	90	10.0	40.4	750	73.7	120.0
9:54	410	25.0	90	10.0	40.7	750	73.7	120.0
9:59	410	25.0	90	10.0	40.9	750	73.7	120.0
10:04	410	25.0	90	10.0	40.9	750	73.7	120.0
10:09	410	25.0	90	10.0	40.9	750	73.7	120.0
10:14	410	25.0	0	10.0	44.6	750	76.5	120.0
10:19	410	25.0	0	10.0	53.4	750	78.8	120.0
10:24	410	25.0	0	10.0	58.6	750	83.0	120.0
10:29	410	25.0	0	10.0	61.6	750	92.9	120.0
10:34	410	25.0	0	10.0	63.4	750	100.0	9.6
10:39	410	25.0	0	10.0	64.5	750	100.0	5.1
10:44	410	25.0	0	10.0	65.2	750	100.0	5.0
10:49	410	15.0	0	10.0	63.1	750	100.0	5.4
10:54	410	15.0	0	10.0	60.0	750	100.0	5.9
10:59	410	15.0	0	10.0	58.1	750	100.0	6.3
11:04	410	15.0	0	10.0	57.1	750	100.0	6.6
11:09	410	15.0	0	10.0	56.5	750	100.0	6.8
11:14	410	15.0	0	10.0	56.2	750	100.0	7.1

Figure 4-6. Output File for Predictive Example. (Continued)

APPENDIX A

TROUBLESHOOTING

DYNAMF's execution is regulated by a series of error criteria that prevents misuse of the program and prevents the program from performing calculations that are outside of acceptable ranges. These error criteria are continually applied to calculated values and input variables and when an error is detected, the user is warned by an appropriate message that appears on the screen. The table below shows the error messages which can appear and the response which will eliminate the error.

List of Error Messages and Recommended Solutions

Error Message	Variable Checked	Solution to Problem
Unrealistic Input Value for Conductor Diameter...	Conductor Diameter	Select an O.D. of the conductor which is greater than zero, but less than the diameter of an individual core or conductor strand. O.D. of conductor must be less than 3.0 inches
Unrealistic Input Value for Core Strand Diameter...	Core Strand Diameter	Select core strand diameter that is between 0 and 0.5 inch but less than the O.D. of the conductor
Unrealistic Input Value for Conductor Strand Diameter...	Conductor Strand Diameter	Select a conductor strand diameter that is between 0 and 0.5 inch but less than the O.D. of the conductor
Unrealistic Input Value for Number of Core Strands...	Number of Core Strands	Select an integer value that is positive, but less than 300
Unrealistic Input Value for Number of Conductor Strands...	Number of Conductor Strands	Select an integer value that is positive, but less than 300
Unrealistic Input Value for A.C. Resistance.	A.C. Resistance	Select a positive value

Please Check Input Value of A.C. Resistance...	A.C. Resistance	Skin effect calculated from input values of A.C. resistance and calculated value of D.C. resistance is outside of reasonable range. Check A.C. resistance value and adjust
Unrealistic Input Value for Latitude...	Latitude	Select a value between 0 and 90°
Unrealistic Input Value for Longitude...	Longitude	Select a value between 0 and 360°
Unrealistic Input Value for the Azimuth of Conductor...	Conductor Azimuth	Select a value between 0 and 180°
Unrealistic Input Value of Angle of Conductor with Horizontal...	Conductor Inclination	Select a value between -90 and +90°
Input Value of Elevation has been set...	Elevation	Select a value greater than 0, but less than 25,000 ft.
Unrealistic Input Value for Solar Absorptivity of Conductor...	Solar Absorptivity	Select a value between 0 and 1.0
Unrealistic Input Value for Emissivity of Conductor...	Infrared Emissivity	Select a value between 0 and 1.0
Conductor Temperature is Above 400°C and is Out of Range...	Conductor Temperature	The program is attempting to calculate a conductor temperature which exceeds 400°C. Reduce the conductor current or increase the conductor size.
Unrealistic Input Value for the Month of the Year...	Month	Select an integer value between 1 and 12
Unrealistic Input Value for the Day of the Month...	Day	Select an integer value between 1 and 31
Unrealistic Input Value for the Hour of the Day...	Hour	Select an integer value between 0 and 23
Unrealistic Input Value for the Minute of the Hour...	Minute	Select an integer value between 0 and 59

Unrealistic Input Value of Wind Speed...	Wind Velocity	Select a positive value, but less than 85 ft/sec (58 mph)
Unrealistic Input Value for Wind Direction	Wind Direction	Select a value between 0 and 360^{o}
Unrealistic Input Value for the Ambient Temp....	Air Temperature	Select a value between -50 and +50^{o}C
Unrealistic Input Value of Conductor Current...	Current	Select a positive value that is less than 100,000 amps
Unrealistic Input Value for the Emergency Limiting Temperatures...	Limiting Temperature	Select a value between 20 and 300^{o}C
The Conductor Temperature is Already Above the Emergency...	Limiting Temperature	Select a value for the emergency limiting temperature that exceeds the present conductor temperature when in predictive mode.
Unrealistic Input Value of Multiplier for Overload Current...	Overload Current Ratio	Select a value which is greater than 1.0
Unrealistic Input Value for the Printing Time...	Printing Interval	Select a value that is between 1 and 60 minutes.
Unrealistic Input Value for the Time Interval...	Time Interval	Select a value that is between 1 and 60 minutes.

APPENDIX B

LIST OF CONDUCTOR CODE NAMES

A separate subprogram within DYNAMP contains conductor properties (outer diameter, number of strands, diameter of strands and A.C. resistance) and these properties may be automatically entered into the input file by specifying the conductor code name. The conductor code names that are contained in the subprogram are listed below for each of six different conductor types.

ACSR
(Aluminum Conductor Steel Reinforced)

JOREE	FALCON	MARTIN	BLUEJAY	HAWK
KINGFISHER	NUTHATCH	BITTERN	FINCH	HEN
BLUEBIRD	PARROT	PHEASANT	ORTOLAN	CHICKADEE
CHUKAR	BOBOLINK	BUNTING	CURLEW	BRANT
ASPWING	PLOVER	GRACKLE	NONAME	IBIS
CRANCRAKE	DIPPER	GREBE	ROOK	LARK
ANIL	CRANE	CROW	GOOSE	MERLIN
QUCODE	COOT	STILT	GROSBEAK	WIDGEON
SEDINAL	TERN	STARLING	EGRET	LINNET
CARDBIRD	TURBIT	REDWING	SCOTER	TURKEY
CANADA GANSER	PUFFIN	BUTEO	DUCK	BRAHMA
BRIARSTONE	CONDOR	GULL	PEACOCK	DORKING
ROBIN	CUCKOO	FLAMINGO	SQUAB	PARTRIDGE
CARDINAL	DRAKE	GANNET	TEAL	PENGUIN
REDSTART	MALLARD	SWIFT	WOODDUCK	QUAIL
CANARY	SKIMMER	KINGBIRD	OSPREY	RAVEN
GRACKLE	ORIOLE	GUINEA	PARAKEET	ROBIN
LINNET	PHOEBE	LEGHORN	THRASHER	SPARROW
[illegible]	GADWALL	MINORCA	KIWI	SPARATE
[illegible]	OSTRICH	PETREL	JUNCO	SWAN
[illegible]AN	PIPER	GROUSE	PIGEON	SWANATE
[illegible]ER	WAXWING	COCHIN	DOTTEREL	ACSR/EHS

AAC
(1350-H19 Aluminum Core and Conductor)

BLUEBONNET	CATTAIL	HAWTHORN	GOLDENTUFT	ROSE
TRILLIUM	PETUNIA	MARIGOLD	CANNAPEACH	BELL
COSMOS	NASTURTIUM	LARKSPUR	DAFFODIL	SYRINGA
COWSLIP	VIOLET	BLUEBELL	TULIP	COSMOS
JESSAMINE	FLAG	HAWKWEED	PEONY	IRIS
COREOPSIS	VERBENA	CAMELLIA	LAUREL	ANEMONE
GLADIOLUS	ORCHID	GOLDENROD	DAISY	LILAC
CARNATION	MEADOWSWEET	MAGNOLIA	VALERIAN	ARBUTUS
COLUMBINE	MISTLETOE	SNAPDRAGON	SNEEZEWORT	ASTER
NARCISSUS	HYACINTH	COCKSCOMB	OXLIP	POPPY
DAHLIA	ZINNIA	CROCUS	PHLOX	PANSY

AAAC
(6005-H19 Aluminum Core and Conductor)

SOLAR	KITTLE	KENCH	REX	REDIAN
SPAR	KOPEAK	KAKI	RAGOUT	RADAR
DUNE	KAYAK	KAZOO	REDE	RAMIE
UBLE	KIBE	REMEX	REDE	RATCH

AAC
(6201-T81 Aluminum Core and Conductor)

PELEY	DARIEN	BUTTE	ANAHEIM	ALTON
IRO	FLINT	ALLIANCE	AZUSA	AKRON
NTON	ELGIN	AMHERST	AMES	

ACAR
(6201-T81 Aluminum Core and 1350-H19 Aluminum Conductor)

2300_1	RAIL	BUNTING1	GROSBEAK1
2300_2	RAIL2	BUNTING2	GROSBEAK2
2300_3	RAIL3	BUNTING3	GROSBEAK3
BLUEBIRD1	RAIL4	BLUEJAY1	GROSBEAK4
BLUEBIRD2	RAIL5	BLUEJAY2	DOVE1
BLUEBIRD3	DRAKE1	BLUEJAY3	DOVE2
KIWI1	DRAKE2	CURLEW1	PELICAN1
KIWI2	DRAKE3	CURLEW2	PELICAN2
KIWI3	DRAKE4	CURLEW3	MERLIN1
CHUKAR1	DRAKE5	CURLEW4	MERLIN2
CHUKAR2	DRAKE6	ORTOLAN1	ACAR900.1
CHUKAR3	TERN1	ORTOLAN2	ACAR2000.1
ARWING1	TERN2	ORTOLAN3	ACAR1600.1
ARWING2	TERN3	CARDINAL1	ACAR1000.1
ARWING3		CARDINAL2	ACAR1000.2
TERN1		CARDINAL3	ACAR1200.1
TERN2			ACAR1200.2

DRAFT

CONDUCTOR TEMPERATURE RESEARCH

DRAFT

Research Project 2546
Final Report June 1987

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Prepared by
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Atlanta, Georgia
and
Georgia Power Company
Atlanta, Georgia

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NOMENCLATURE

Symbol	Description
A	cross-sectional area
c_p	specific heat at constant pressure
D	diameter
Gr	Grashof Number
g	acceleration of gravity
h	convective heat transfer coefficient
I	current
J_0	zero order Bessel function of the first kind
k	thermal conductivity
k_s	skin effect
m	mass of the conductor per unit length
N	number of strands
Nu	Nusselt number
Pr	Prandtl Number
Q"	radiant energy incident on conductor per unit area
Re	Reynolds number
R	electric resistance per unit length of conductor or gas constant
r	radius
SE	skin effect
T	temperature
t	time
V	velocity
Y	age of conductor in years
Y_0	zero order Bessel function of the second kind
z	elevation above sea level

Greek Symbols	Description
α	atmospheric lapse rate
α_s	solar absorptivity of conductor surface
α_1 or α_2	temperature coefficient of resistance
β	thermal coefficient of expansion of air
ϵ_I	infrared emissivity of conductor surface

μ	dynamic viscosity of air
ν	kinematic viscosity of air
ξ	quantity defined in Eq. 39
ρ	resistivity or density
σ	Stefan-Boltzmann constant
ϕ	angle between the wind direction and the axis of the conductor
ω	angle between wind direction and normal to conductor

Subscripts	Description
AC	alternating current
c	conductor strand property
conv	convection
DC	direct current
dif	diffuse solar contribution
dir	direct solar contribution
f	film value
gen	generated heat inside conductor
m	area excluding air gaps between strands
o	sea level value
rad	radiation
s	supporting strand property
sun	relates to solar value
t	total value
∞	ambient conditions

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SECTION 1

INTRODUCTION

Historically most electric utilities have thermally rated their overhead transmission and distribution lines on the basis of a desired maximum operating temperature and an assumed set of conservative, fixed weather conditions. As a result, most lines are thermally underutilized for a majority of the time. Recently more utilities have recognized the significant economic benefits associated with the ability to determine conductor temperatures and line clearances based on existing weather conditions. A real-time thermal line model can, therefore reveal excess current carrying capacity and it can permit safe system operation without exceeding temperature and ground clearance limits.

The objective of this project was to develop an experimentally verified computer program that is capable of predicting the real-time ampacity of overhead conductors. The result is a program for modeling conductor DYNamic AMPacity, DYNAMP, which is part of the TLWorkstation^{TM} software package. DYNAMP solves the basic energy balance on a unit length of conductor and it includes convection and radiation from the surface of the conductor, energy generation inside the conductor due to I^2R heating and storage of energy within the conductor resulting from the thermal capacitance of the conductor mass. The details of the energy balance and the mathematical techniques used to solve for the conductor temperature as a function of weather conditions and current are outlined in Section 3.

The temperatures predicted by DYNAMP have been verified by a test program utilizing a full-scale outdoor instrumented test span. The test span was operated over a four year period and temperatures were measured by thermocouples attached to two different conductor sizes. The experimental effort to verify the program results appears in Section 5.

As part of a critical span analysis, weather data were collected at four remote weather stations within a twenty-five mile radius of the test span. The remote station weather data were used in DYNAMP and the predicted line temperatures at

each remote site were compared to the temperatures measured at the test span. The results were statistically analyzed to show how different weather conditions can produce variations in span-to-span conductor temperatures. These data were also used in conjunction with a sensitivity analysis that predicts those weather and operating conditions that have the greatest influence on the location of a critical span.

A final objective of this project was the evaluation of available line monitors that attach to the conductor and measure temperatures in real-time. Several monitors were collected and evaluated at the outdoor test span. One monitor was attached to the conductor and temperatures measured with this monitor were compared with thermocouple measurements and DYNAMP's predicted values. In addition, this monitor was also mounted on several energized lines in Kansas as part of a project funded by KEURP. A detailed discussion of the line monitors appears in Section 9.

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SECTION 2

ASSESSMENT OF STATE OF THE ART

SEMINARS

A review of the state of the art in the dynamic rating of overhead lines revealed an unusual situation. On one hand, a utility survey conducted at the beginning of the project (see next section) indicated that there was considerable research ongoing in the area of real-time ampacity determinations. On the other hand, most utilities either had not initiated a real-time rating system or they lacked the expertise to formulate a transient ampacity model for their transmission and distribution systems.

To present the latest in real-time rating research and to disseminate information on ampacity schemes, a two day seminar was held. The joint ampacity seminar sponsored by EPRI, Georgia Power Company, Georgia Institute of Technology, and the Aluminum Association of America was held in Atlanta May 20-21, 1986. An excellent group of engineers and scientists performing research in or involved with the line rating area volunteered to present technical papers on their work. These seminars were held to stimulate interest in dynamic line ratings and to bring together individuals working these areas. Over one hundred people attended. Forty one utilities were represented by individuals in Electrical Engineering, System Operations, Planning and Operation and Maintenance. Fourteen different manufacturers were represented. Also in attendance were several consultants, several engineers in academic positions and a few members of the press.

The proceedings of the seminars entitled "Effects of Elevated Temperature Operation on Overhead Conductors and Accessories" and "Real-Time Ratings of Overhead Conductors" are available from EPRI as a special publication. The titles of the individual papers are given in the Appendix.

UTILITY SURVEY

In the initial stages of the project a survey was written to solicit input from a broad cross-section of utility engineers. The survey was specifically formulated to determine how the various utilities would ultimately use a real-time ampacity program. It was also designed to provide utility input in the early development stages of the ampacity program. The responses to the questions in the survey were then used to provide direction in writing the program so that it would receive the greatest possible use throughout the industry. A copy of the survey and the responses to all questions is placed in the Appendix.

The questions in the survey came from a combination of sources. Some questions were taken from a survey conducted by CIGRE', others were formulated to determine the present state of ampacity models used in the industry while other questions were inserted to determine needs for future ampacity models. Some questions were specifically inserted to determine the interest in and the demand for line instrumentation which could be used to predict real-time conductor temperatures.

The survey was subdivided into four parts.

Section I - Operation of Transmission and Distribution Systems
Section II - Steady State Ampacity Calculating
Section III - Real-Time Ampacity Calculations
Section IV - Ampacity Instrumentation and Critical Span Analysis.

In addition to the survey, five companies were selected for site visits and discussions were held concerning real-time ampacity models. All discussions at these site visits were recorded on tape. During these visits rating manuals were collected and compared. The five companies visited were:

Illinois Power Company, Decatur
Wisconsin Electric Company, Milwaukee
Pacific Gas and Electric Company, San Francisco
Idaho Power Company, Boise
Tampa Electric Company, Tampa

A list of people who either participated in the discussions during the site visits or completed the questions on the survey are listed in the Appendix. The list includes 48 engineers representing 23 different companies.

As expected, the response to the survey revealed a broad range of interest in a few areas, but there were several items that received unanimous opinions.

None of the utilities responding to the survey had the capability to measure the temperatures of their overhead transmission conductors; and yet every company expressed a desire to utilize a real-time ampacity program to predict actual conductor temperatures when such a program becomes available. Another question receiving a unanimous vote was the one which asked which system of units was preferred when using an ampacity program. All companies expressed a desire to use the English system of units except the unit for temperature. Most preferred to use the Fahrenheit degree when measuring the air temperature and the Celsius degree when specifying the conductor temperature. One final area that received a unanimous vote concerned the way in which the responding utilities rated their overhead conductors. All companies rated their systems on the basis of a single winter and a single summer air temperature and all companies considered that the air flow is perpendicular to the conductor. With the exception of one company, all those who responded to the survey indicated that they do not consider separate daytime and nightime ratings. None of the companies calculated a fault condition ampacity value. And finally, none of the utilities considered magnetic heating, evaporative cooling or a temperature gradient within the conductor when they calculate ampacity values.

Questions other than those mentioned in the previous paragraph received less than unanimous votes, and as a result these results became somewhat more difficult to interpret. For example, several of the questions were formulated to determine whether most of the utilities would have the facilities to monitor weather conditions within their service area, because a real-time ampacity program would require up-to-date weather data as input. Seventy-five percent of the companies that responded to these questions stated that they had the capability to monitor weather conditions within their service area in at least one location. It is probably safe to say that no company would presently have a sufficient number of weather stations to provide adequate input to a real-time ampacity program. In

other words, if a company wished to achieve a reasonable accuracy from a real-time ampacity model over their entire service area, they would certainly have to install a greater number of weather stations.

Seventy-five percent of the utilities stated that they had the ability to calculate their own steady-state ampacity value. The form of the steady-state ampacity values that are used by the various utilities were quite different. Ampacity values were primarily in the form of tables and they appeared to be fairly evenly split between the Aluminum Association tables, manufacturer's tables and tables that were developed with internally generated computer programs. The most frequently mentioned program was one based on the House and Tuttle method. The conditions used in the ampacity tables are fairly consistent among those utilities that have steady-state ampacity programs. Two-thirds of those who responded report that they calculate their ampacity values for a constant wind velocity of 2 ft/sec. The remainder used a velocity of 4.4 ft/sec with the exception of one company which calculated ampacity based on a zero wind velocity. Two-thirds of the companies accounted for solar heating of the conductor while the remainder ignored the influence of the sun when determining the temperature of the conductor. With the exception of one company, the emissivity and absorptivity of the conductor, regardless of whether the conductor is aluminum or copper, is assumed to be 0.5. None of the companies considered the effect of age on the radiative properties of the conductor.

All companies calculated a normal ampacity rating, while only seventy-five percent calculated an emergency ampacity rating. Normal ampacity values corresponded to a wide range of conductor temperatures, the most common value being 75°C. The maximum temperature used for a normal rating was 120°C while some companies provided for different ratings depending upon the construction of the conductor. Of those companies that consider emergency ratings, the most commonly mentioned limiting time for an emergency rating was two hours. Other values for a limiting time during which an emergency overload would be tolerated ranged between 30 minutes and 4 hours and one company permitted emergency conditions to exist for up to 500 hours per year. The temperatures that were acceptable during the emergency current overload ranged between 80°C and 140°C with the most commonly mentioned figure being 93°C. Some companies have established different acceptable values for emergency ampacity calculations depending upon different types of conductor

construction. They have established relatively low values for emergency temperatures for hard drawn copper conductors and progressively higher acceptable values for AAC and ACSR conductors.

The reasons that the various utilities gave for selecting the maximum limiting conductor temperature were split among the following factors: clearance, loss of strength, creep, degradation of splices and economic factors. The two factors that did receive a slightly greater consideration were clearance and loss of strength. Several of the utilities that were interviewed made the statement that limiting ampacity values should ultimately be set on the basis of clearance and other factors should play only a very minor role in dictating operating temperatures of the conductor. Several utilities had experienced splice failures throughout their overhead network and they were being forced to face the problem of replacing or upgrading numerous splices. These particular utilities obviously placed a greater emphasis on selecting a limiting temperature that would protect the integrity of their splices and they placed very little importance on clearance as a factor which should dictate maximum operating temperatures.

While practically all of the companies that were surveyed had the ability to calculate steady-state ampacity values, very few had the capability to predict real-time ampacity values. One-fourth of the utilities have programs to calculate real-time ampacity values. All companies would use a real-time ampacity program if it were available and they would expect that program to predict the conductor temperature to within ± 5°C of the actual temperature. Two companies placed a high priority on developing a real-time ampacity program, seven felt that they had a moderate priority for such a program and four placed a low priority on such a program. The highest priority for the development of a real-time ampacity program came from the operating engineers followed by planning engineers. The design engineers felt they would be the ones who would be least likely to use the program. When asked what type of computing equipment would be most likely used to run the program, the response showed an even split between a mainframe computer and a personal computer.

The form of the output information provided by the computer program seemed to depend greatly upon who would be using the program. The operating engineers made a very strong case for a program output that was very simple and easy to

interpret. They were not particularly concerned about a program that was very general or one which would apply to the broadest range of conductor geometries and weather conditions. When asked how the program should convey real-time information to the user, the operating engineer showed a strong preference for the output of a single value that would predict the time a conductor would reach a predetermined limiting temperature. The designers and planners, on the other hand, were not concerned about the simplicity of the output, but they expressed a desire that the program be general enough to handle all types of conductors and all possible weather conditions that could possibly exist within their service area.

Even though none of the utilities surveyed are presently measuring the temperature of any of their conductors and even though only two out of eleven companies that were surveyed said they had any future plans to install temperature measuring devices on their energized lines, seventy percent of the utilities said that they would purchase line monitoring equipment if it were reliable and readily available at a cost between $10,000 to $15,000. The number of devices that these utilities would purchase ranged between two and twelve. The most commonly used reason for purchasing this type of equipment was to have a means of checking the accuracy of a real-time ampacity computer model. Most people felt that when the instruments had proven the accuracy of the model, they would not continue to use the devices on their system. When asked whether an on-line instrument or a computer model would provide the greatest confidence is knowing the temperature of an overhead conductor, the response was equally split. It appears that design engineers place more confidence in a computer model while planners and operating engineers seem to feel more confident with an on-line monitor.

The questions regarding the concept of critical span and how the industry views this concept seem to indicate that most utilities either do not subscribe to the concept of a critical span, or if they do, they are not sure how to utilize the concept when rating their transmission network. Only thirty percent of the companies utilize the concept of a critical span in determining the real-time rating of their network. Of these companies some had difficulty defining what actually constitutes a critical span, but the most frequently given definition of a critical span was simply the span which had the highest temperature. Most of those who subscribed to the concept of a critical span simply said that a critical

span was one that had experienced thermal problems in the past and a few people said that a critical span could be identified by locating those lines that had experienced exceptional load growth in the past.

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SECTION 3

DEVELOPMENT OF DYNAMP

INTRODUCTION

Steady state models for conductor ampacity have been widely used throughout the electric power industry and they remain the backbone for most design and operating decisions relating to the thermal behavior of overhead systems. These models assume that each change in conductor current is immediately followed by a corresponding change in conductor temperature. In reality the temperature of the conductor changes gradually over a period of time after a change in current. This delay is a result of the thermal capacitance of the conductor which is a function of environmental and physical factors.

Real-time ampacity models account for conductor capacitance and they therefore can reveal increased system capacity, particularly under emergency loading conditions, that would otherwise remain unutilized when a steady-state ampacity model is employed. The energy stored in the conductor during the time of the transient is often sufficient to provide the operator time to make more effective load management decisions before the conductor reaches a predetermined limiting temperature. Armed with a real-time ampacity model, an operating engineer can efficiently and safely distribute energy over the transmission network without exceeding sag limits or without jeopardizing the strength of the conductors.

A real-time ampacity model can provide other advantages to an operating engineer. Steady-state ampacity models, based on a set of conservative weather parameters, may often predict that major tie lines between utilities operate at their ultimate capacity. If a real-time rating program is applied to the same lines, it will frequently reveal a strikingly different conclusion. By using actual weather conditions and by accounting for the thermal capacity of the line, the real-time program can show a reserve capacity for transmission of power and thereby provide the operator with a potential to generate increased revenue.

A real-time ampacity program helps not only the operating engineer, but it also provides a useful and valuable tool for planning and design engineers. If a planner or designer has a knowledge of the transient thermal behavior of the overhead network, he is better able to make capital intensive decisions. For example, a real-time ampacity model could greatly influence the decision between purchasing additional right-of-way and installing a new line or simply utilizing an established line coupled with resagging, reconductoring or rebuilding the existing towers.

The initial work on the steady-state ampacity models first appeared in the 1920's [1-5], even though extensive work had been completed prior to that time on the convective heat transfer from cylinders to air. Thermal models for the calculation of the conductor temperature became more sophisticated [6-12] and naturally more complicated to use. Real-time ratings of overhead conductors were introduced [13-21] in the 1960's. At the present time most transient ampacity models are so complex that they require the aid of a digital computer for their solution. The numerical complexity associated with a real-time rating program is a distinct disadvantage and it will obviously discourage some from attempting to use real-time rating results.

This report describes a user-friendly computer program that will overcome the problems with the complexities of previous real-time ampacity models. The program requires a minimum amount of input information and it will calculate steady-state, real-time and predictive conductor temperatures for any realistic weather conditions and loading history. The temperatures predicted by the program have been verified in a test program utilizing a full-scale outdoor test span which has been operated for over four years. The results of the experimental verification phase of the project have shown that the program can accurately predict the temperatures of a wide variety of conductor designs for any reasonable current and weather conditions.

MATHEMATICAL BASIS OF PROGRAM

The thermal model that forms the basis for DYNAMP starts with a basic energy balance on a representative segment of the conductor. The model considers

convection and radiation from the surface of the conductor, energy generation inside the conductor due to I^2R heating and storage of energy within the conductor due to its thermal capacitance. All of these components are subject to time dependent variables such as wind speed and direction, ambient temperature, and line current, so the solution is transient in nature.

The strands of the conductor are assumed to be in good thermal contact so that the temperature of all strands is identical. Therefore, the model is unable to predict the conductor temperature when the aluminum strands expand to such as extent that they are no longer in contact with the steel core. Under these conditions there can be significant temperature differences between the strands. The implications of this assumption are discussed more thoroughly in Section 4.

An energy balance on a unit length of conductor results in a governing equation which can be solved for the conductor temperature, T, as a function of time, t, the mass of the conductor, m, specific heat of the conductor c_p, and the various contributions to the heat input to the line. The energy balance equation is:

$$mc_p \frac{dT}{dt} = Q_{gen} + Q_{sun} - Q_{rad} - Q_{conv} \qquad (1)$$

This equation is identical to the steady-state energy balance on a conductor except that the term on the left side of the equation has been inserted to include energy stored in the conductor during periods of transient operation.

The symbols mc_p in Eq. 1 represent the average mass-specific heat product of the composite conductor on a per unit length basis. The symbol Q_{gen} represents the rate of heat generation per unit length due to current in the line. This term is a function of both time and conductor temperature became the current is a function of time and the conductor resistance is a function of temperature. The term Q_{sun} is the rate of both direct and diffuse solar energy absorbed per unit length of conductor. This term is a function of time due to the variation of solar energy incident on the conductor during the day. The term Q_{rad} is the emitted radiation from a unit length of conductor. This term is a function of the conductor and environment temperatures. Finally the symbol Q_{conv} represents the rate of heat removed from the surface of the conductor to the ambient air by the convection

mode. This term is a function of the conductor temperature and the instantaneous weather conditions which are functions of time.

The generation term in Eq. 1 is calculated from

$$Q_{gen} = I^2(t)R_{AC}(T) \tag{2}$$

The AC resistance of the conductor is assumed to be a linear function of the conductor temperature and accounts for the skin effect and line reactance.

The sun's energy which is absorbed per unit length of conductor (Q_{sun}) is attributed to two distinct sources. The first is energy directly incident on the conductor and the second is due to solar energy which first reflects from the surroundings before striking the line. The total rate at which solar energy is absorbed by a unit length of conductor is then

$$Q_{sun} = D\alpha_s \left[Q_{dir}(t) + \pi\, Q_{dif}(t)\right] \tag{3}$$

where D is the conductor diameter and α_s is the solar absorptivity of the line. The direct incident solar flux (Q_{dir}) and diffuse incident solar flux (Q_{dif}) are functions of date, time of day, latitude and longitude of the line, orientation of the line and amount of cloud cover. For the purposes of formulating a computer program to calculate both of these terms, it was found [20] that the standard solar flux equations given in Ref. 16 were satisfactory in estimating the total amount of solar energy corrected for atmospheric absorption that is incident on the line.

The conductor will emit radiant energy from its surface to the surroundings and this heat loss per unit length of conductor is given by the term Q_{rad} in Eq. 1. Since the conductor has a relatively low temperature, the predominant portion of the emitted radiant energy is in the infrared wavelength range. Therefore the correct line radiative property to be used in calculating the emitted energy is the infrared emissivity (ϵ_I). Assuming the portion of the surroundings that has a view of the line has the same temperature as the ambient air, T_∞, the net radiant energy exchange between the conductor and the surroundings per unit line length is

$$Q_{rad} = \epsilon_I D \pi \sigma [T^4 - T^4_\infty(t)] \quad (4)$$

where σ is the Stefan-Bolzmann constant and T is the absolute temperature of the conductor.

The convection term, Q_{conv}, in Eq. 1 must account for free convection when the wind velocity is zero and for forced convection effects when wind exists. The heat removed from the surface of the conductor per unit length by convection to the ambient air in terms of the convective heat transfer coefficient, h, is

$$Q_{conv} = \pi D h(t) [T - T_\infty(t)] \quad (5)$$

The convective heat transfer coefficient is a complex function of conductor temperature, air temperature, wind velocity and wind direction. For still air conditions the convective heat transfer coefficient is a function of the Prandtl number and Grashof number and for forced convection the Reynolds number replaces the Grashof number as the significant dimensionless group.

Substitution of Eqs. 2, 3, 4 and 5 into the basic energy balance equation (Eq. 1) results in

$$mc_p \frac{dT}{dt} = I^2(t)R_{AC}(T) + D\alpha_s[Q_{dir}(t) + \pi Q_{dif}(t)] - \epsilon_I D\pi\sigma[T^4 - T^4_\infty(t)] - \pi Dh(t)[T - T_\infty(t)] \quad (6)$$

which is the fundamental differential equation solved by DYNAMP for the conductor temperature T. This equation is a first order, ordinary, non-linear differential equation. Since Eq. 6 is non-linear, it is not reasonable to expect a closed-form analytical solution for the conductor temperature as a function of time. However, standard numerical techniques such as a Runge-Kutta method [32] can be used to provide a value for the conductor temperature at discrete time intervals. The numerical techniques to solve this equation is discussed in more detail in a later section.

Conductor Properties

Equation 6 contains five properties of the conductor; mass per length m, specific heat at constant pressure c_p, electric resistance per unit length R_{AC}, infrared emissivity ϵ_I and solar absorptivity α_s. The program calculates each one of these properties from given input information or it requires the user to provide the properties as input information.

The mass per unit length of the conductor is calculated from the number of strands N, diameter D of each of the strands and the density ρ of the conductor material. The mass per unit length of the conductor is determined from (see Nomenclature for definition of symbols).

$$m = \rho_s N_s \frac{\pi D_s^2}{4} + \rho_c N_c \frac{\pi D_c^2}{4} \qquad (7)$$

where the lay factor values from Ref [30] have been used to correct the length of strands for a unit length of conductors.

The program uses the following values of density:

$\rho = 2703$ kg/m^3	for 5005-H19, 1350-H19 and 6201-T81 aluminum
$\rho = 8890$ kg/m^3	for copper
$\rho = 7780$ kg/m^3	for steel
$\rho = 6590$ kg/m^3	for alumoweld

The specific heat at constant pressure for each type of conductor material is assumed to be a linear function of conductor temperature. The program uses the following expressions for c_p:

$c_p = 0.32236\ T + 929.4$	for 5005-H19, 1350-H19 and 6201-T81 aluminum
$c_p = 0.02512\ T + 422.0$	for copper
$c_p = 0.47517\ T + 441.2$	for steel
$c_p = 0.4061\ T + 621.0$	for alumoweld

where T is in ^{o}C and c_p is in J/kg•^{o}C.

When a conductor consists of one type of material for the supporting strands and a second type of material for the conducting strands, the expression for the mass-specific heat product of the composite conductor is

$$mc_p = (m\ c_p)_c + (m\ c_p)_s \tag{8}$$

The electric resistance per unit length of conductor is calculated by using the input values of conductor type and the AC resistance at $20^{o}C$. The program calculates the D.C. resistance at $20^{o}C$ from the conductor cross-section and the electric resistivity for each conductor type. The calculated D.C. resistance and input value for A.C. resistance are used to calculate a skin effect and this value is assumed to be a constant at all temperatures.

The D.C. resistance at an arbitrary temperature T per a unit length of conductor is calculated from the expression

$$R_{DC}(T) = \frac{\rho(T)}{A} = \frac{\rho(20)[1 + \alpha(T - 20)]}{N\pi D^2/4} \tag{9}$$

and the lay factor values from Ref. [30] have been used to correct for the length of strands for a unit length of conductor. The A.C. resistance can be calculated from the known skin effect (SE),

$$R_{AC}\ (T) = (SE)\ R_{DC}\ (T) \tag{10}$$

Equation (10) is used to calculate the electric resistance of both the supporting and conducting strands. The resistance for a unit length of the composite structure is then calculated from

$$R(T) = \frac{R_c(T)\ R_s(T)}{R_c(T) + R_s(T)}$$

because the two materials form a parallel resistance to the flow of the total current.

The resistivity and temperature coefficient of resistivity for the various conductor materials are given in Table 1.

Table 1. Electrical Resistivity and Temperature Coefficient of Resistivity for Common Conductor Materials (From Ref. 23).

Material	$\rho(20^{o}C) \times 10^{6}$ ohm•cm	$\alpha \times 10^{3}$ ohm•cm/^{o}C
1350-H19 Aluminum	2.817	4.04
6201-T81 Aluminum	3.284	3.47
5005-H19 Aluminum	3.223	3.53
Hard Drawn Copper	1.777	3.81
Alumoweld	8.401	3.60
Steel	21.551	3.2

The two radiative properties needed in the thermal model (Eq. 6) are the solar absorptivity and infrared emissivity of the surface of the conductor. The emissivity is the ratio of the radiant energy emitted by a surface to the radiant energy emitted by a black surface at the same temperature. The emissivity depends upon the material of the emitting surface, its temperature, surface condition and wavelength distribution of the emitted energy. Since the temperature of a conductor rarely exceeds 150^{o}C, the emitted energy lies predominantly in the infrared wavelength ranges. As a result, the appropriate emissivity for use in the emitted radiated energy term is the infrared emissivity.

Two studies [25,26] considered a large number of ACSR samples removed from service. The results showed that the emissivity of the aluminum ranged between 0.23 for a new conductor to 0.98 for an aged, heavily oxidized surface. As expected, the measured emissivity data showed a significant amount of scatter. Nevertheless the emissivity values can be predicted with enough accuracy for the purposes of an approximate ampacity model. The recommended curve from Ref. 25, for ACSR conductors energized above 15 kV in most industrial, as well as rural atmospheres is [25]

$$\epsilon_I \simeq 0.23 + \frac{0.70\ Y}{1.22 + Y} \qquad (11)$$

where Y is the age of the conductor in years. For ACSR conductors energized below 15 kV, the emissivity variation with conductor age was determined to be [25]

$$\epsilon_I \simeq 0.23 + \frac{1.38Y}{75.5 + Y} \qquad (12)$$

for $0 \leq Y \leq 95$.

Like aluminum conductors, the infrared emissivity for copper conductors is a function of the surface contamination and the extent of oxidization of the conductor surface. The following values are recommended [23 and 27] for use in ampacity calculations utilizing copper conductors.

$\epsilon_I \simeq 0.80$ for black, heavily oxidized surfaces
$\epsilon_I \simeq 0.50$ for normally oxidized surfaces
$\epsilon_I \simeq 0.30$ for lightly oxidized surfaces
$\epsilon_I \simeq 0.03$ for polished, new surfaces

The incident radiant energy on the conductor lies predominantly in the wavelength range from the visible portion of the spectrum into the near infrared. Therefore, the parameter which dictates the percent of the total incident solar energy that is absorbed by the conductor is the solar absorptivity. The trend in the solar absorptivity can be predicted with some reliability by observing the color of the conductor. Surfaces which are highly corroded and dark in color tend to have values of solar absorptivity which approach 1.0. More polished and highly reflecting surfaces have much lower absorptivities.

Values for the solar absorptivity for both aluminum and copper conductors can be approximated by using the results presented in Ref. 29

$$\alpha_S \simeq \epsilon_I + 0.2 \qquad (13)$$

with the restriction that $\alpha_S \leq 1.0$.

Convection

An accurate model for determining the convective heat transfer coefficient is imperative for an accurate prediction of the thermal behavior of an overhead conductor. Unfortunately the convective heat transfer from a conductor is a complex phenomena that does not easily lend itself to a simple analysis. As the wind velocity approaches zero, the heat transfer from the conductor occurs by free convection and the convection heat transfer coefficient in terms of the Nusselt number, Nu, is given by a functional relationship which can be written in terms of the Grashof number, Gr, and the Prandtl number, Pr, or

$$Nu = f(Gr, Pr) \tag{14}$$

where

$$Nu = hD/k \tag{15}$$

$$Gr = \frac{g\beta(T - T_\infty)D^3}{\nu^2} \tag{16}$$

and

$$Pr = \frac{\mu c_p}{k} \tag{17}$$

For common sizes of overhead conductors and for surface temperatures between 0°C and 100°C it can be shown that

$$10^4 \leq GrPr < 10^9 \tag{18}$$

and for this range of GrPr the Nusselt number for free convection to air from a horizontal cylinder is given by [27]

$$Nu = 0.53\,(GrPr)^{1/4} \tag{19}$$

A computational difficulty exists in free convection that does not exist in the case of forced convection. Equations 16 and 19 show that the free convection heat transfer coefficient depends upon the temperature of the conductor. However, the

temperature of the conductor cannot be calculated until the value of h is known. Therefore, the problem requires an iterative solution involving repeated calculations of h and T until convergence is satisfied. This difficulty does not arise in forced flow, because the convective heat transfer coefficient is independent of conductor temperature as long as thermodynamic properties of air are assumed to be independent of temperature.

When the wind velocity across the conductor is not zero, the heat transfer to the air occurs by forced convection and the relationship of the Nusselt number becomes a function of both the dimensionless Reynolds and Prandtl numbers or

$$Nu = f(Re,Pr) \tag{20}$$

where

$$Re = \frac{VD}{\nu} \tag{21}$$

For forced convection from a horizontal cylinder to air flowing perpendicular to the axis of the cylinder, the Nusselt number correlation can be estimated by the expression (See Ref. 16).

$$Nu=10^{[-0.07043 + 0.3153\ \log Re + 0.03553(\log Re)^2]} \tag{22}$$

For wind directions other than perpendicular to the conductor, Eq. 22 can be corrected by using the expression [16]

$$\frac{Nu(\omega)}{Nu(\omega=0)} = 1.194 - \sin\omega - 0.194\cos 2\omega + 0.368\sin 2\omega \tag{23}$$

where ω is the angle between the normal to the surface of the conductor and the direction of the air flowing across the conductor. The denominator in Eq. 23, $Nu(\omega=0)$, is the Nusselt number for perpendicular flow.

Properties of Air

The Nusselt, Prandtl, Grashof and Reynolds numbers contain properties of air that are functions of the average air temperature. The program calculates these

properties at a film temperature which is the average temperature of the ambient air and the conductor or

$$T_f = \frac{T + T_\infty}{2} \tag{24}$$

The thermal conductivity in W/m°C of air at the film temperature in °C is

$$k = 0.023681 + 7.232 \times 10^{-5} T_f - 2.763 \times 10^{-8} T_f^2 \tag{25}$$

The dynamic viscosity in J•s/m^3 of air at the film temperature in °C is

$$\mu = 17.456 \times 10^{-6} + 3.954 \times 10^{-8} T_f \tag{26}$$

The property group $g\beta/\nu^2$ in the Grashof number is

$$\frac{g\beta}{\nu^2} = \frac{9.807}{T_f} \left[\frac{\rho}{\mu} \right]^2 \tag{27}$$

where the film temperature is in K and the property group has units of $K^{-1}m^{-3}$. The density of the air used in this group is a function of the air temperature and elevation of the conductor.

If the atmosphere is assumed to be a stagnant ideal gas with a linearly varying temperature, then the density as a function of film temperature T_f, elevation z, lapse rate of the atmospheres α, acceleration of gravity g, gas constant of air R, sea level temperature T_o and sea level pressure P_o is [31]

$$\rho = \frac{P}{RT_f} = \frac{P_o}{RT_f} \left[\frac{T_o - \alpha z}{T_o} \right]^{g/\alpha R} \tag{28}$$

where

α = 0.0065 K/m

P_o = 101.3 kPa

T_o = 288 K

$g = 9.807\ m/s^2$

$R = 0.287\ kPa \cdot m^3/kg \cdot K$

The units of both T_o and T_f in this expression are K and ρ is in kg/m^3.

The final air property needed to evaluate the convective heat transfer coefficient is the Prandtl. The program assumes a constant Prandtl number over the entire range of normal film temperatures [27].

$$Pr = 0.71 \tag{29}$$

Radiation

The final parameter in Eq. 6 that influences the ampacity and transient rating of an overhead conductor is the rate of solar energy per unit area incident on the surface of the conductor. This parameter is a complex function of the orientation of the line relative to the position of the sun, the extent of cloud cover and the composition of the atmosphere. A detailed discussion of these parameters is presented in Ref. 16. The incident solar energy external to the atmosphere is approximately 1353 W/m^2. The solar radiation that reaches the surface of the earth is partially attenuated by the atmosphere and it is composed of a direct or beam component and a diffuse component as can be seen in Eq. 6. The program utilizes the line orientation, date, time of day and location of the conductor on the surface of the earth to calculate the clear-sky diffuse and direct radiant energy incident on the conductor. The program utilizes the equations developed in [16] and calculates both the direct and diffuse solar energy incident on the conductor.

Numerical Methods

Before Eq. 6 can be solved for the conductor temperature, a single initial temperature must be determined. The program assumes that the initial condition for the differential equation is the steady-state temperature corresponding to the first set of conductor currents and weather conditions. Therefore the initial condition is

$$T = T_o\ (0) \tag{30}$$

where T_o is the steady-state temperature of the conductor corresponding to the solution of the equation

$$I^2(t)R_{AC}(T) + \alpha_s D[Q_{dir}(t) + \pi Q_{dif}(t)]$$

$$- \epsilon_I D\pi\sigma[T^4 - T_\infty{}^4(t)] - \pi Dh(t)[T - T_\infty(t)] = 0 \qquad (31)$$

Since this equation is algebraic, but non-linear, it can be solved using a traditional Newton-Raphson numerical technique [32].

Once the initial temperature has been determined, the real-time conductor temperature can be calculated from Eq. 6 by using a Runge-Kutta [32] numerical scheme. This technique is very efficient and it has been used for a wide variety of weather conditions and current distributions which vary with time. The solution for the conductor temperature has always been numerically stable and is strictly convergent in all cases. The program has been terminated and restarted numerous times in the middle of a set of transient input data and the temperatures have always converged to measured temperatures in less than ten minutes of real time.

CAPABILITIES OF DYNAMP

DYNAMP is a very versatile program with broad capabilities. It can determine both steady-state ampacity values as well as transient or real-time temperatures of overhead conductors. In addition, it has a predictive mode of operation that permits the user to calculate the temperature of the conductor in a future time when the conductor is subjected to a step change in current. The predictive mode of operation is designed to help a operator who wants to anticipate the temperature of the conductor when it experiences current transients that are typical during emergency operation.

DYNAMP is capable of predicting temperatures for seven different types of conductors

1. ACSR
2. AAC

3. AAAC (6201-T81)
4. ACAR
5. All copper
6. Alumoweld
7. AAAC (5005-H19)

Properties of these conductors are automatically entered by the program once the user specifies the conductor type.

The program can calculate the conductor temperature for any reasonable set of weather and current conditions. Wind velocities can range from zero to 58 mph (85 ft/sec) and air temperatures can be between -50°C and +50°C. The program calculates a clear sky incident solar energy for any location on the surface of the earth and the value for solar energy is used as part of the energy input to the conductor. DYNAMP automatically calculates sunrise and sunset times for the specified latitude and longitude of the line.

DYNAMP contains a number of warning and error messages to assure that the program is used properly and it can accurately predict the conductor temperature. Various error and warning messages will appear on the screen if input values cause the program to attempt unreasonable calculations.

The execution of DYNAMP from the operators standpoint has been simplified as much as possible. A user-friendly front-end program written in Professional Applications Development Language (PADL) has been developed by Power Computing Company (PCC) and it greatly simplifies the program operation. The PADL interactive program is similar in format to other programs that are part of the TLWorkstation™ software. Incorporated into the user interface program is a series of help files that are designed to aid the user when problems arise with the program operation.

The input information to DYNAMP has been simplified as much as possible. The program contains a separate subroutine that can provide conductor properties for a wide variety of conductor designs. Each property set is designated by the code name that is frequently used to specify different types and designs of conductors. By simply specifying the conductor code name, the program will search the

conductor property file and select the proper input properties. This program feature streamlines the program operation and helps prevent user errors in the conductor data input information.

The operation of DYNAMP is described in a separate document [33]. This document is a users manual that provides detailed instructions on how to run the program and how to interpret the results.

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SECTION 4

TEMPERATURE GRADIENTS WITHIN OVERHEAD CONDUCTORS

Early ampacity models used to calculate the relationship between the current in an overhead conductor and the conductor temperature ignored radial temperature variations that may have existed within the conductor. This assumption could easily be accepted, because overhead conductors are relatively small and they consist of materials that have very high thermal conductivities. As a result, the internal resistance to the conduction of heat across the cross-section of a conductor is extremely small and temperature gradients, if they exist, should be negligible.

More recent work in the ampacity area [38] has revealed that the isothermal assumption may not be justified under all conditions and some experimental measurements have suggested that temperature differences in a conductor may reach as high as 5-15°C. Naturally if such temperature differences do exist, the question of how they may affect previous ampacity calculations is an important one. This section addresses that question and the thermal model proposed here will permit the determination of the precise form and magnitude of the temperature differences that exist in stranded conductors. Furthermore, the model will illustrate the errors produced in ampacity calculations as a result of assuming the conductor is isothermal. The thermal model is used to calculate the temperature differences that exist in a stranded conductor as a function of current, conductor construction and weather conditions.

Even though a stranded conductor is composed of materials with high thermal conductivities, the composite conductor has an effective thermal conductivity which is significantly less than the value for a solid metallic material due to the air encapsulated between the strands. Also, the effective thermal conductivity is a strong function of any factor which influences the amount of air trapped between adjacent strands. For example, it would be natural to expect that the existence of temperature differences in a conductor would be strongly dependent upon the conductor construction (compact ACSR or ACSR/TW as opposed to normal stranded ACSR) and the conductor tension. Furthermore the effective conductivity of a stranded conductor can be a strong function of the conductor

temperature, because excessive temperatures could produce a situation known as "birdcaging" in which adjacent strands actually do not touch each other. Under these extreme conditions, the effective thermal conductivity of the conductor can be quite low and significant temperature differences can exist in a conductor.

To obtain an expression of the temperature variation within a composite conductor, a governing differential equation was derived which assures conservation of energy within the conductor. To simplify the resulting equation, the following assumptions were made:

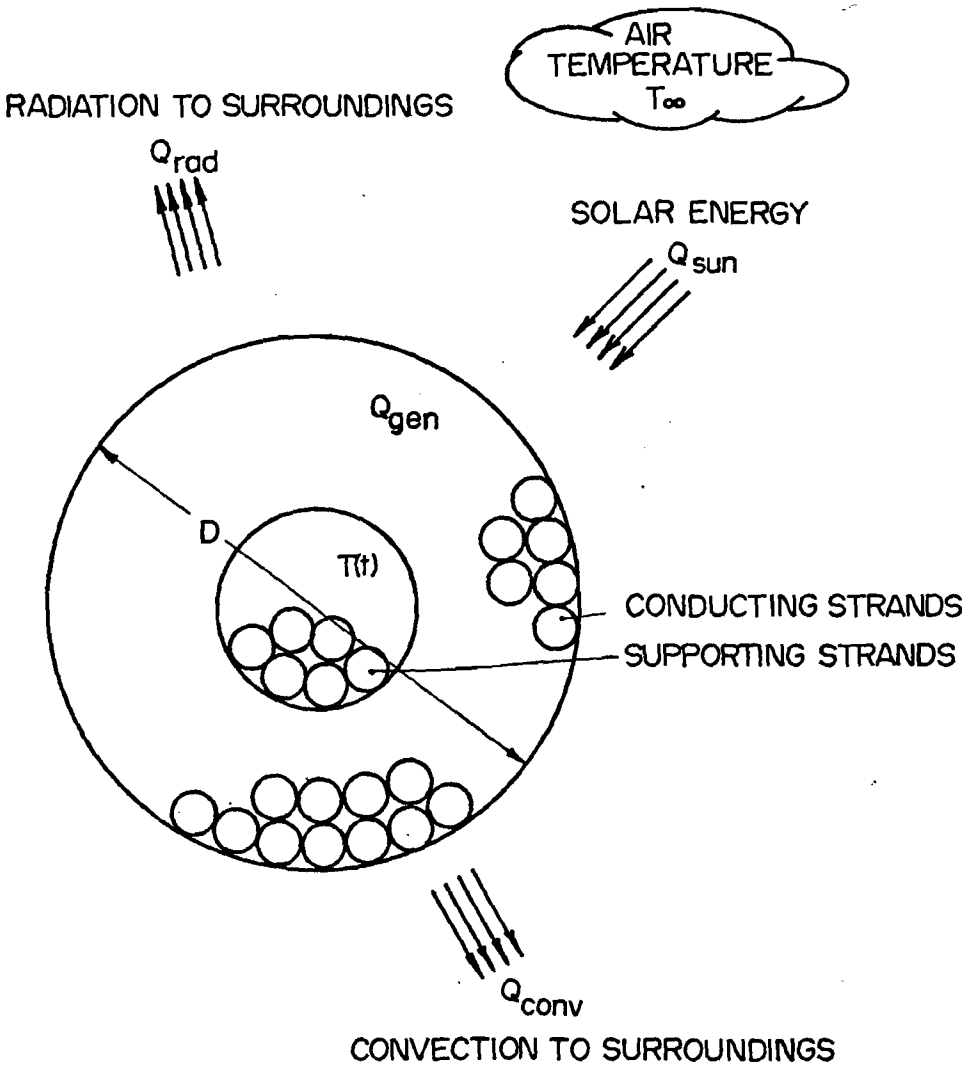
a. The conductor current is steady and the weather conditions are independent of time.
b. The temperature of the conductor is only a function of radial position.
c. The thermal conductivity of the conductor materials is constant.
d. The electrical resistance of the conductor varies linearly with temperature.
e. The I^2R heat is generated uniformly throughout each material of the conductor.

Applying these assumptions, the differential equation for the local conductor temperature within a conductor carrying a current I is (See Ref. [27], page 50)

$$\frac{k}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \frac{I^2R}{A} = 0 \tag{32}$$

where the conductor material has a cross-sectional area A, a resistance per unit length of R and a thermal conductivity of k.

In a composite conductor such as in an ACSR conductor, the majority of the current is carried by the low resistance conducting strands and only a small fraction of the total current circulates through the high resistance supporting steel strands. A sketch of a typical composite conductor consisting of centrally located supporting strands surrounded by conducting strands is shown in Fig. 1. If the total current passing through the composite conductor is I_t, then the current through the conducting strands I_C with a resistance of R_C and the current through the supporting strands I_S with a resistance R_S are



CONDUCTOR PROPERTIES:

m = Mass

C_p = Specific Heat

R_{AC} = AC Resistance

α_s = Solar Absorptivity

ϵ_I = Infrared Emissivity

T = Temperature

Figure 1. Energy Balance on a Conductor

$$I_s = I_t\left(\frac{R_c}{R_s + R_c}\right) \tag{33}$$

$$I_c = I_t\left(\frac{R_s}{R_s + R_c}\right) \tag{34}$$

The results of Eqs. 33 and 34 illustrate that the current distribution in one material of the composite conductor is a function of the temperature of both materials because the resistances are functions of temperature. Therefore the determination of the temperature distribution in both the supporting and conducting materials becomes an exercise of simultaneously solving Eq. 32 when it is applied to both materials. To simplify matters without a significant loss in accuracy, values for the two currents, I_c and I_s, can be approximated by using values of the two resistances in Eqs. 33 and 34 evaluated at an approximate temperature. This assumption has shown [35] to produce errors in the current distribution in the two layers of conductor that are less than 2%, even if errors in the assumed temperature are as high as 30°C.

Using the current distribution given by Eqs. 33 and 34, the conservation of energy equations when applied to both materials become independent of each other with the results

$$\frac{k_s}{r}\frac{d}{dr}\left[r\frac{dT_s}{dr}\right] + \frac{I_s^2}{A_s}\frac{\rho_s}{A_{ms}}\left[1+\alpha_s\left[T_s-293\right]\right] = 0 \qquad \text{for supporting strands} \tag{35}$$

and

$$\frac{k_c}{r}\frac{d}{dr}\left[r\frac{dT_c}{dr}\right] + \frac{I_c^2}{A_c}\frac{\rho_c}{A_{mc}}\left[1+\alpha_c\left[T_c-293\right]\right] = 0 \qquad \text{for conducting strands} \tag{36}$$

where T is measured in degrees Kelvin, the subscripts s and c refer to properties of the supporting and conducting strands respectively, ρ is the electrical resistivity at 20°C, α is the temperature coefficient of resistance, A is the cross-sectional area including air gaps and A_m is the cross-sectional area of the metallic material excluding air gaps.

The solutions to Eqs. 35 and 36 in terms of the four constants of integration C_1, C_2, C_3 and C_4 are

$$T_s = T_\infty\left[C_1 J_0\left(\xi_s\right) + C_2 Y_0\left(\xi_s\right) - \left[\frac{1-293\ \alpha_s}{T_\infty \alpha_s}\right]\right] \tag{37}$$

and

$$T_c = T_\infty\left[C_3 J_0\left(\xi_c\right) + C_4 Y_0\left(\xi_c\right) - \left[\frac{1-293\ \alpha_c}{T_\infty \alpha_c}\right]\right] \tag{38}$$

where

$$\xi = \left[\frac{I^2 \rho \alpha r^2}{k A A_m}\right]^{1/2} \tag{39}$$

and J_0 and Y_0 are the zero order Bessel functions of the first and second kind.

The values for the constants C_1 through C_4 in Eqs. 37 and 38 can be determined from the boundary conditions. The four boundary conditions for the problem are

a. $T(0)$ is finite (40)

b. $T_s\ (r_{os}) = T_c(r_{os})$ (41)

c. $$k_s \frac{dT_s}{dr}\left(r_{os}\right) = k_c \frac{dT_c}{dr}\left(r_{os}\right) \tag{42}$$

d. $$-k_c \frac{dT_c}{dr}\left(r_{oc}\right) = \epsilon\sigma\left[T_c^4\left(r_{oc}\right) - T_\infty^4\right] + h\left[T_c\left(r_{oc}\right) - T_\infty\right] - \alpha\ Q''_{sun} \tag{43}$$

These boundary conditions ensure that there is no thermal contact resistance between the supporting and conducting strands and they also ensure that the heat conducted up to the surface of the conductor is removed from the surface by convection and radiation to the surroundings. The analysis assumes that the sun creates an incident radiant flux on the outer surface of the conductor equal to Q''_{sun}. The portion of this incident solar energy that is absorbed by the conductor is dictated by the absorptivity, α, of the conductors surface. The

emissivity of the conductor is ϵ and the surroundings are assumed to be radiatively black at the ambient air temperature which is equal to T_∞. The values for both Q''_{sun} and h are calculated using the procedure outlined in the previous section.

Application of these four boundary conditions results in four non-linear algebraic equations that can be used to solve for the four constants of integration in Eqs. 37 and 38. Details of these equations and the solution by Bairstows method [32] are given in Ref. [35]. Once the values for the four constants are determined as a function of conductor properties, current in both materials and the state of the thermal environment of the conductor, Eqs. 37 and 38 can be used to calculate the radial temperature distribution in both the supporting and conducting strands.

One remaining factor that must be addressed before the local temperatures in the conductor can be calculated is the proper value for the thermal conductivity of the strands. The thermal conductivity of solid conductors are quite high as can be seen from the values in Table 2. On the other hand the air that exists been the strands is an excellent insulator and has a very low thermal conductivity. The appropriate thermal conductivity values to be used in Eqs. 37 and 38 are effective values that consider the fact that the heat generated in the metal must be conducted through a composite material consisting of both air layers and the cylindrical metallic strands. Therefore the appropriate thermal conductivities to be used in Eqs. 37 and 38 are the effective conductivities of metallic strands interspersed with encapsulated air layers located between the strands. Douglass [36] has compiled a number of effective conductivity values for ACSR conductors from a number of sources. Effective thermal conductivity values range from 1.2 to 5.6 W/m•°C depending upon the size of conductor, tension in the conductor, stranding and state of the thermal environment. Values of effective conductivity seem to center around a value of 2 W/m•°C for aluminum strands and 1.5 for steel strands. These values will be used in the results presented in the next section.

Table 2. Values of Thermal Conductivity at 20°C
from [23] pg. 24 and [27] pgs. 511 and 520.

Material	k(W/m•°C)
Copper	410
Aluminum	
1350-H19	234
6063-T6	201
Galvanized Steel	40
Air	0.025

A computer program was developed to determine the temperature distribution in the conductor. Input variables to the program include geometric, thermal and electric properties of both the supporting and conducting strands and the total current in the composite conductor. Additional input parameters include values which quantify the thermal environment of the conductor such as wind velocity and direction, solar flux and ambient air temperature.

Using the mathematical model described in this section, the temperature in an overhead conductor can be calculated as a function of radial position. Then by comparing the temperature-current relationship for this model with one like DYNAMP which assumes an isothermal conductor at any instant in time, it is possible to determine whether temperature gradients inside the conductor will have an influence on the ampacity of a conductor. To distinguish between the two models, the one based on Eqs. 37 and 38 will be referred to as the Non-Isothermal Model, because it accounts for radial temperature gradients in the conductor. The model described in the previous section and based on the DYNAMP program will be designated as the Isothermal Model, because it assumes the conductor is uniformly at a single temperature.

The Non-Isothermal Model has been applied to a wide variety of ACSR, AAC and all copper conductors. A few of the more important conclusions that can be drawn from these results are illustrated in the figures presented in this section. A more extensive set of results is provided in Ref. [35].

Figure 2 illustrates some of the typical results for five ACSR conductors with widely varying sizes. Characteristics of these conductors are given in Table 3. The results in Fig. 2 show the centerline and outer surface temperatures predicted by the Non-Isothermal Model and the average conductor temperature predicted by the Isothermal Model. These results were calculated for varying currents with fixed conductor properties and fixed environmental conditions which are specified in the figure.

Table 3. Physical and Electrical Characteristics of Typical ACSR Conductors. (From [23] Table 4-14A)

Name	Size (kcmil)*	Stranding	Dia Cond Strands (in)	Dia Supp. Strands (in)	OD (in)
Linnet	336.4	26/7	0.1137	0.0884	0.720
Hawk	477	26/7	0.1354	0.1053	0.858
Rook	636	24/7	0.1628	0.1085	0.977
Drake	795	26/7	0.1749	0.1360	1.108
Falcon	1590	54/19	0.1716	0.1030	1.545

* 1 kcmil = 7.854×10^{-4} in^2

Conductor: 1350-H19 Aluminum
Supporting strands: Galvanized steel

The results of Fig. 2 show that the maximum temperature difference across the cross-section of a conductor increases as the current increases. This temperature difference can be as high as 7°C for the conductor sizes and current levels investigated. The figure also shows that the ampacity values predicted by the Isothermal Model are very close to the ones predicted by the Non-Isothermal Model. In other words, previous ampacity models which are based upon an isothermal conductor will provide satisfactory results and the slight increase in accuracy provided by a non-isothermal ampacity model is not warranted when the additional complexity of the Non-Isothermal Model is considered. However, it should be pointed out that the isothermal ampacity model will not provide a conservative estimate of the conductor temperature. It merely provides an average conductor temperature and strands near the center of the conductor will be hotter than it

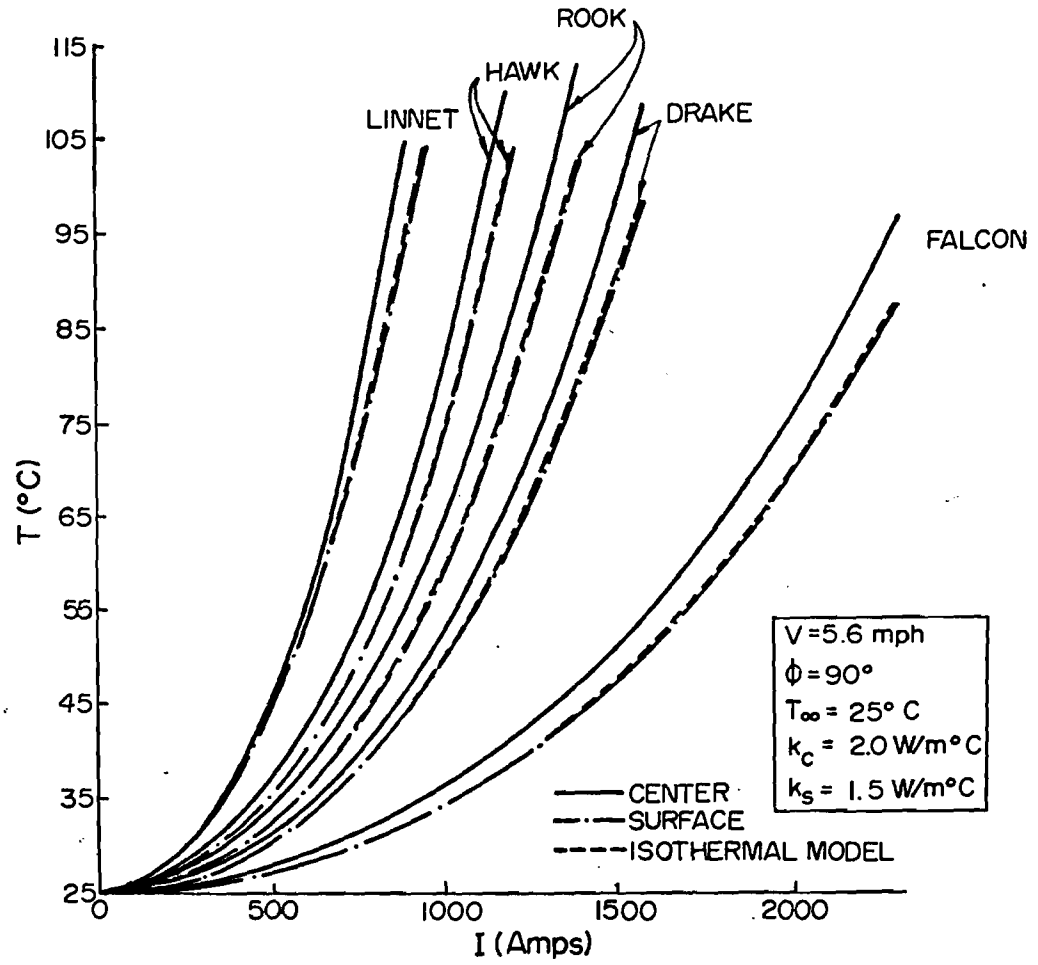


Figure 2. Temperature as a Function of Current for Several ACSR Conductors

predicts even though the temperature of the center strands will be underestimated by only a few degrees in worst of conditions. For example, the Isothermal Model curves in Fig. 2 show that the 75°C ampacity value for the given conditions and a Hawk conductor is 960 amps. The Non-Isothermal Model reveals that the Hawk conductor with this current will actually have a center temperature of approximately 78.7°C and a surface temperature of about 73.4°C. These figures tend to reinforce the conclusion that ampacity calculations based on an isothermal model are sufficiently accurate for normal rating purposes.

Figure 3 provides an illustration of the radial temperature variation in a typical ACSR conductor. The curve shows that the Drake conductor at 1100 amps results in a maximum difference in conductor temperatures of about 4°C. Furthermore, the temperature is practically isothermal in the steel core and the vast majority of the temperature drop occurs in the aluminum strands.

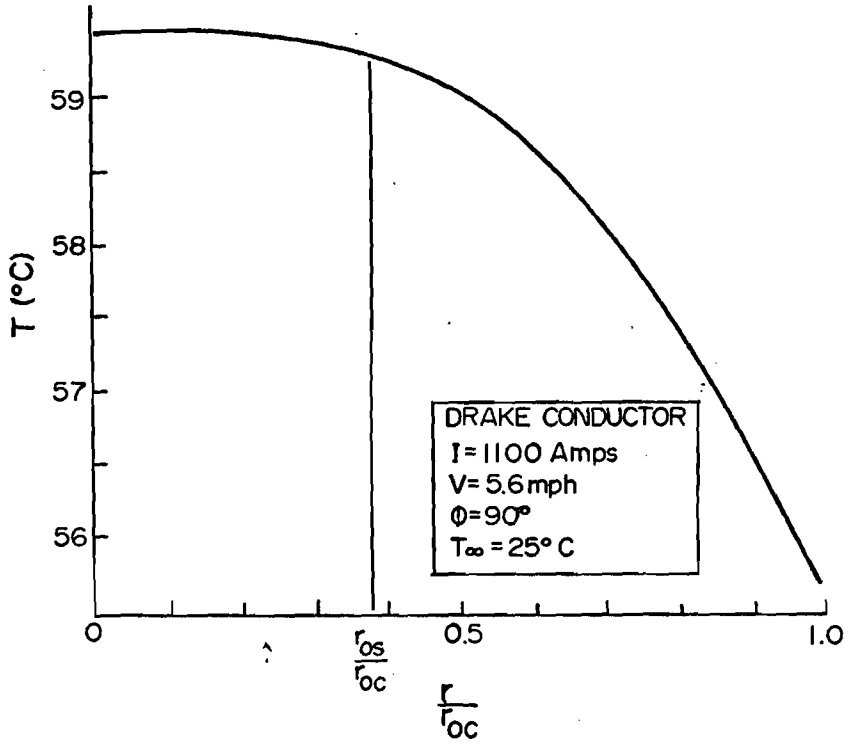


Figure 3. Temperature as a Function of Radius for a Drake Conductor at 1100 amps

Figure 4 shows results similar to the ones in Fig. 2 except for four AAC conductors. The physical and electrical characteristics of these conductors are summarized in Table 4. These results show that temperature differences in AAC conductors rarely exceed 7°C even for conductor temperatures as high as 100°C. The Isothermal Model again predicts temperatures extremely close to the

temperature of the outer surface of the conductor and the Isothermal Model is able to accurately predict ampacity values under the conditions stated in the figure.

When the Non-Isothermal Model is applied to all copper conductors the predicted temperature differences between the centerline and surface of the conductor are about one half the values for AAC and ACSR conductors [35].

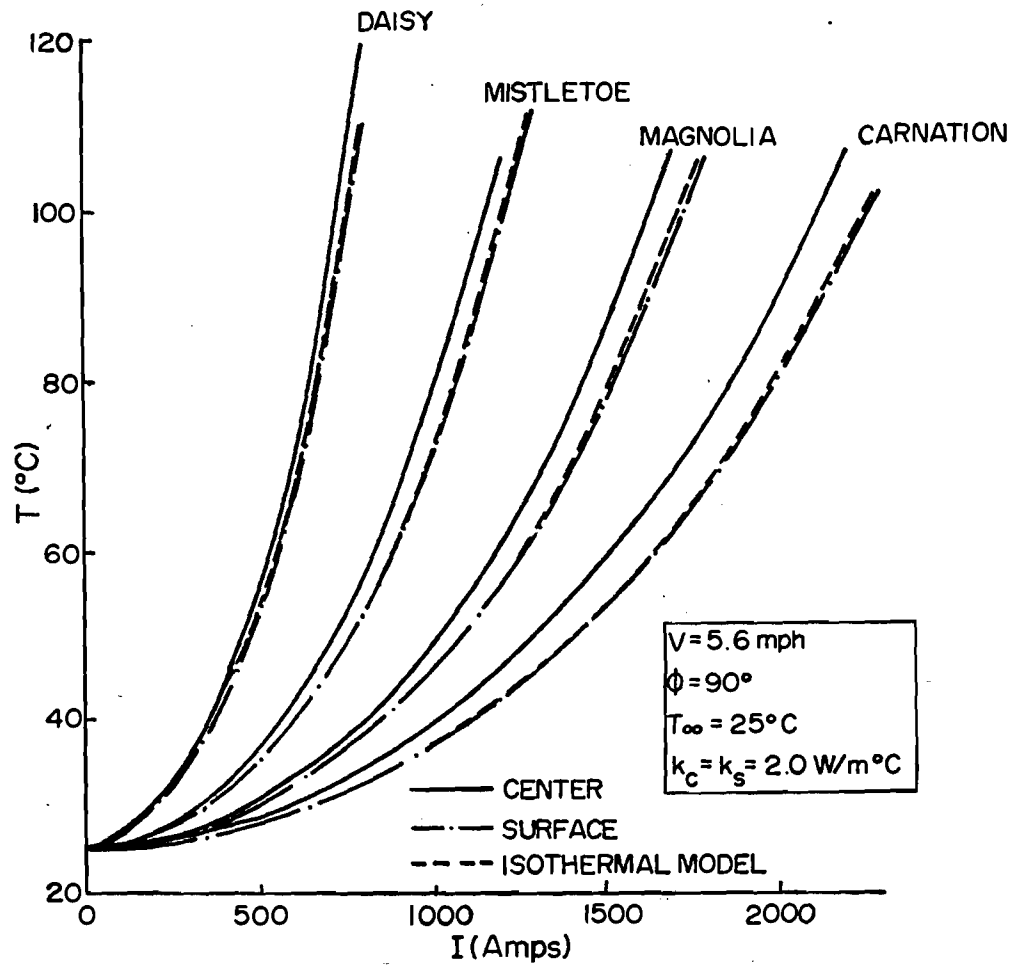


Figure 4. Temperature as a Function of Current for Several AAC Conductors

Table 4. Physical and Electrical Characteristics of Typical AAC Conductors (From [23] Table 4-5).

Name	Size (kcmil)	Strands	Dia of Strands (in)	OD (in)
Daisy	266.8	7	0.1953	0.586
Mistletoe	556.5	37	0.1226	0.858
Magnolia	954.0	37	0.1606	1.124
Carnation	1431.0	61	0.1532	1.379
Conductor and supporting strands: 1350-H19 Aluminum				

The thermal model can be used to investigate the influence that the effective thermal conductivity has on the temperature distribution of a conductor. In Fig. 5 the outer surface and centerline temperatures of a Drake conductor are plotted for a fixed effective conductivity of the supporting strands and a variable effective conductivity of the outer conducting strands. The results show that the value for effective conductivity of the conducting strands has practically no influence on the surface temperature of the conductor. Also significant changes in the effective conductivity of the conducting strands have only a minor influence on the centerline temperature and only as the effective conductivity of the strands drops below a value of about 10 W/m•^{o}C does the center temperature show any significant change. These results imply that conductors with compact segmental strand resulting in reduced air gaps between strands should be an effective method of reducing temperature gradients within a conductor.

In order to more fully understand the impact of the weather conditions on the temperature distribution within an overhead conductor, the program was used to calculate the conductor temperature when the weather conditions were varied. A typical example of this process is shown in Fig. 6 which plots the center and surface temperature of a Drake conductor for constant current and varying wind velocity. The results show the sizeable effect that the wind velocity has on the temperature of the conductor. The conductor temperature with no wind over the surface is approximately 75^{o}C and the average temperature drops to below 35^{o}C when the wind velocity increases to only 5 mph (2.24 m/s). The difference between the surface and center temperatures of the conductor is nearly constant at slightly over 1^{o}C for all wind velocities.

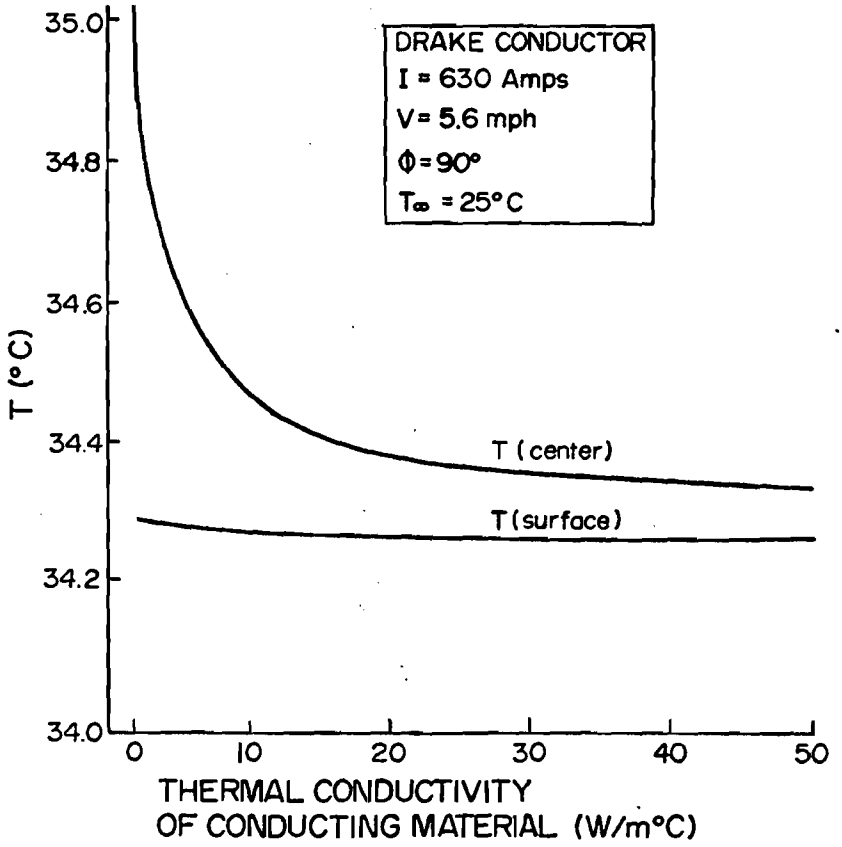


Figure 5. Temperature as a Function of Effective Thermal Conductivity of the Outer Conducting Strands

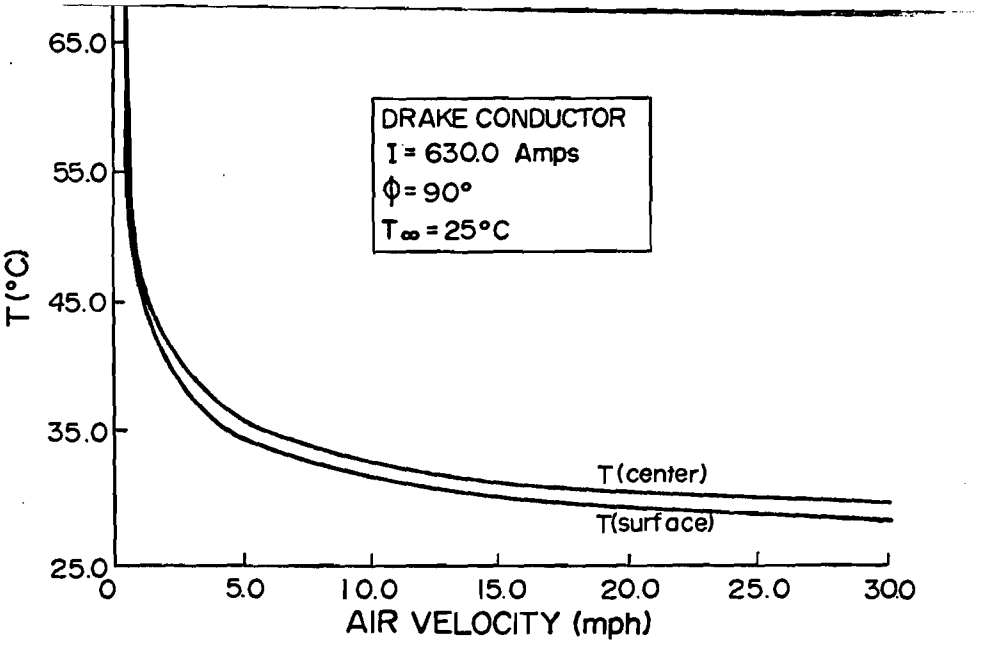


Figure 6. Temperature as a Function of Air Velocity for a Drake Conductor at Constant Current

The results shown in Fig. 7 are similar to those in Fig. 6 except that they are calculated for a varying current and a constant surface temperature of 72.4°C. Maintaining a constant surface temperature requires an increase in conductor current as the air velocity increases. These results show that the difference in the center and surface temperature increases with wind velocity and for a 30 mph (13.4 m/s) wind velocity, the maximum temperature difference within the conductor is approximately 16°C. This is a rather large temperature gradient in a conductor, but it exists under an unusually strong wind and unusually high current load (over 2.2 times the 75°C ampacity value for a Drake conductor at 2 ft/sec wind conditions). These results illustrate that weather conditions which result in a large convective heat loss from the surface of the conductor (high wind velocity and flow normal to the conductor axis) are ones which translate into the largest temperature gradients within the conductor. However, high currents must accompany the high wind velocities in order for the large temperature gradients to exist. Therefore, conductors loaded at normal 2 ft/sec, 75°C ampacity values will be practically isothermal at high wind conditions.

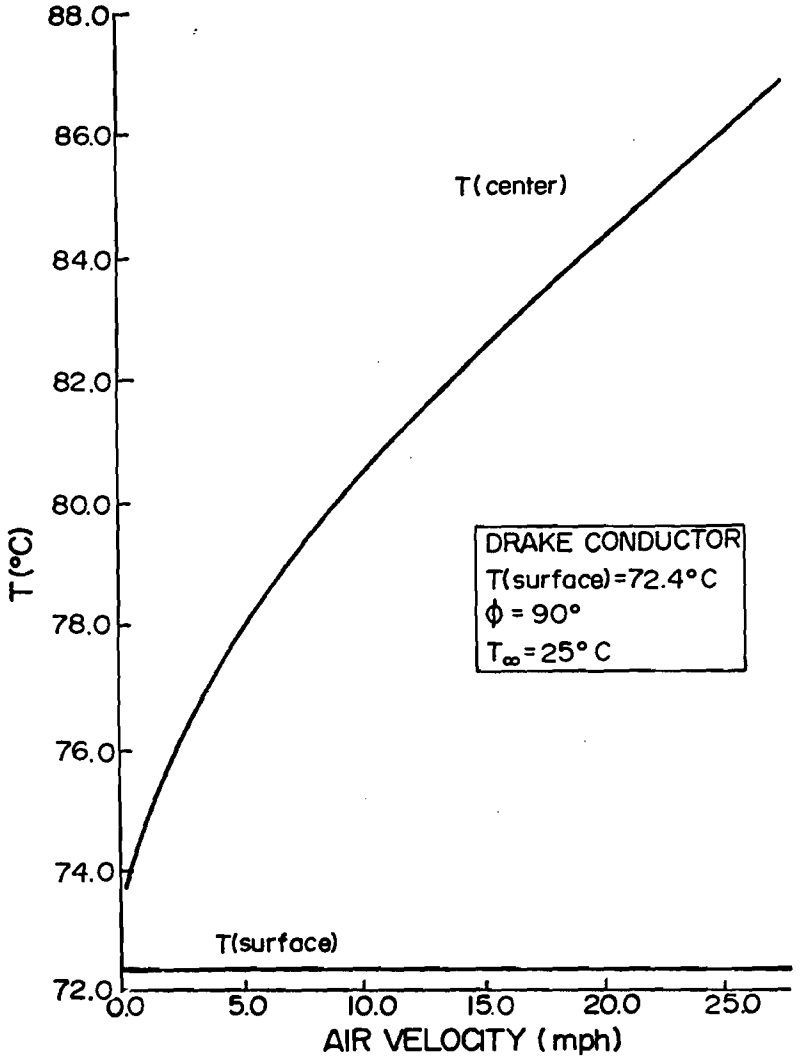


Figure 7. Temperature as a Function of Air Velocity for a Constant Outer Surface Temperature for a Drake Conductor

Several general conclusions can be drawn from the result presented in this section. For typical conductor constructions energized to current levels which produce conductor temperatures less than 100°C and for reasonable weather conditions, the maximum temperature difference that exists in stranded conductors is less than 10°C. However, if conditions reach such a state that birdcaging in the conductor occurs, then temperature differences within the conductor greater than 10°C can easily result.

Conditions which provide for large convective heat losses from the surface of the conductor, such as high wind velocities, will produce large temperature differences in the conductor as long as the average conductor temperature remains constant. Furthermore, temperature differences increase as the current in the conductor increases for constant weather conditions. The vast majority of the temperature drop in an ACSR conductor occurs in the conducting strands while the supporting steel strands are essentially isothermal.

Finally, the results have shown that ampacity models based on the assumption of an isothermal conductor will provide accurate predictions of a conductor temperature that are between the center and surface temperatures. Since the temperature of the center of a stranded conductor is usually only a few degrees Celsius above the temperature predicted by an isothermal model, the errors introduced by the isothermal assumption should not detrimentally affect ampacity calculations.

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SECTION 5
PROGRAM VERIFICATION

To give utility engineers confidence in the DYNAMP computer program, an experimental program was devised to demonstrate the accuracy of the program. Actual experimental data under varying load and weather conditions were recorded during tests conducted at three different locations. Outdoor verification was obtained at the Georgia Power Research Center Test Span where conductor temperatures were measured with thermocouples. Additional outdoor experimental results were obtained at Kansas Gas and Electric on four types of energized conductors using an on line monitor to measure conductor temperatures. The DYNAMP program was also evaluated under controlled conditions in the Pacific Gas and Electric wind tunnel. A description of these three test programs and the results obtained during these tests is presented below.

GEORGIA POWER TEST SPAN

Initially an experimental span of 336 kcmil ACSR Linnet conductor was constructed at the Research Center field site in Forest Park. The 213 meter (700 ft.) span was constructed using 65-foot poles and installed with system line hardware according to Georgia Power specifications (Figure 8). Two conductors were installed and were spaced horizontally 0.46 meters (18 inches) apart. The conductors were oriented in a north-south direction. The Linnet conductor was later replaced with a 1033 kcmil ACSR Curlew conductor. The poles were heavily guyed to reduce pole movement.

A critical component of the test system was the main power circuit. This circuit consisted of a power supply system and an impedance matching system (Figure 9). The current to the line was determined by adjusting the output from a 480 volt power transformer. This transformer fed a series of current transformers which were used to induce current through the conductor at low voltage. The current was measured by running the conductor through a meter grade current transformer.

The impedance matching system was used to couple capacitance to the line so that the self-inductance of the conductors was offset. A capacitor bank was attached

to the high side of a step up transformer which was connected to the line. By switching an optimum number of capacitors into the circuit, a maximum current output of 1800 amperes could be obtained on the Curlew conductor.

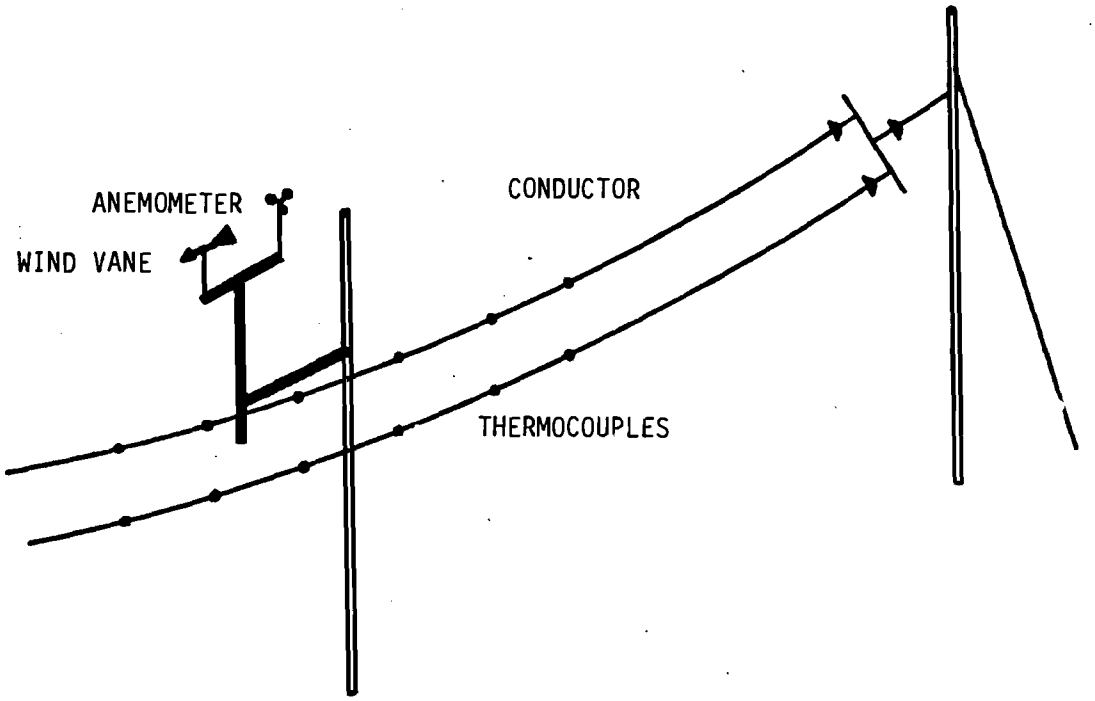

Figure 8. Diagram of Test Span

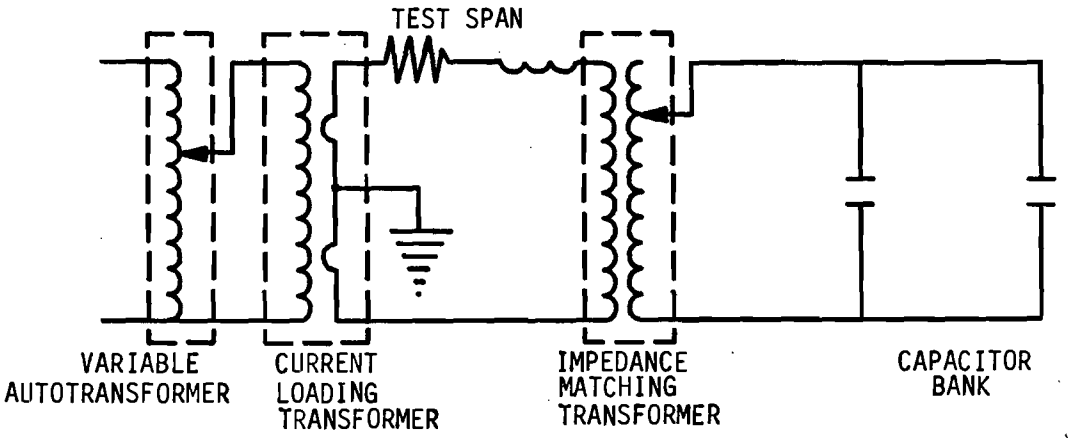

Figure 9. Power Circuit Schematic

Thermocouples were connected directly to the conductor to measure the conductor temperature measurements. Type T sheathed thermocouples with ungrounded junctions were installed. Holes were drilled into the outer strands as well as into the steel core so that the inserted thermocouples could be used to measure core temperatures and surface temperatures. The thermocouple sheaths were 34 mils in diameter and they had a breakdown voltage between the sheath and the thermocouple junction of 600 volts. Since the maximum induced voltage on the line was under 300 volts, the thermocouples could be used quite satisfactorily. Occasionally, a thermocouple would fail and have to be replaced. It is expected that conductor strand movement caused shear to the thermocouples causing the wires to break. Sixteen thermocouples were placed along 90 foot sections of both conductors at center span. The sheathed thermocouples were purchased to meet ANSI error limits.

A Weathertronics meteorological system was installed at center span at conductor height. The station consisted of an ambient temperature thermistor sensor, a relative humidity sensor, a barometer, a tipping bucket rain gauge, a solar sensor, a micro response anemometer and a micro response wind direction vane.

A review of the effects of each meteorological condition on conductor temperature revealed that data from some sensors was not necessary as input to the program. Changes in either the relative humidity or barometric pressure have negligible impact on conductor temperature. Also the radiation measurements were not recorded because the program was designed to calculate the maximum radiation at the line location. This decision elminated the need to know the solar energy flux which is a difficult and expensive measurement to obtain. It was also decided to omit the rainfall as an input to DYNAMP. Therefore the program ignores the significant evaporative cooling that can occur during periods of rain. This assumption leads to conservative results and during rainfall the program can over-estimate the conductor temperature. These last two assumptions greatly simplify the otherwise complex task of collecting weather data for input to the program. As a result, the inputs required for the DYNAMP program are simply the wind speed, wind direction and ambient air temperature.

The thermistor sensor used for ambient temperature measurement is accurate to within 0.1°C. The threshold velocity of the anemometer is 0.5 mph. The accuracy of the anemometer is 0.15 mph or 1% of the full-scale reading, whichever is greater. The cup anemometer gives two contact closures per revolution so that the number of counts per minute is proportional to the wind speed. The threshold

response of the wind vane is 0.5 mph and the resolution is one degree. The output from the microprocessor-based weather station is optically isolated and sent to the data acquisition system via an RS 232 data link. The weather station was calibrated at Weathertronics to standards that are NBS traceable. The calibration of the wind speed output was then checked in three month intervals using a constant speed motor to drive the shaft of the cup anemometer. Practically no drift of the sensors occurred during the time the test span was in operation.

All load control and data collection for the test span were performed using the HP3054 data acquisition system. The system consisted of a Hewlett Packard 9835 Desktop Computer used as a controller, a scanner, a digital voltmeter, a printer/plotter, and custom built interface. Figure 10 is a block diagram of the data acquisition and control structure.

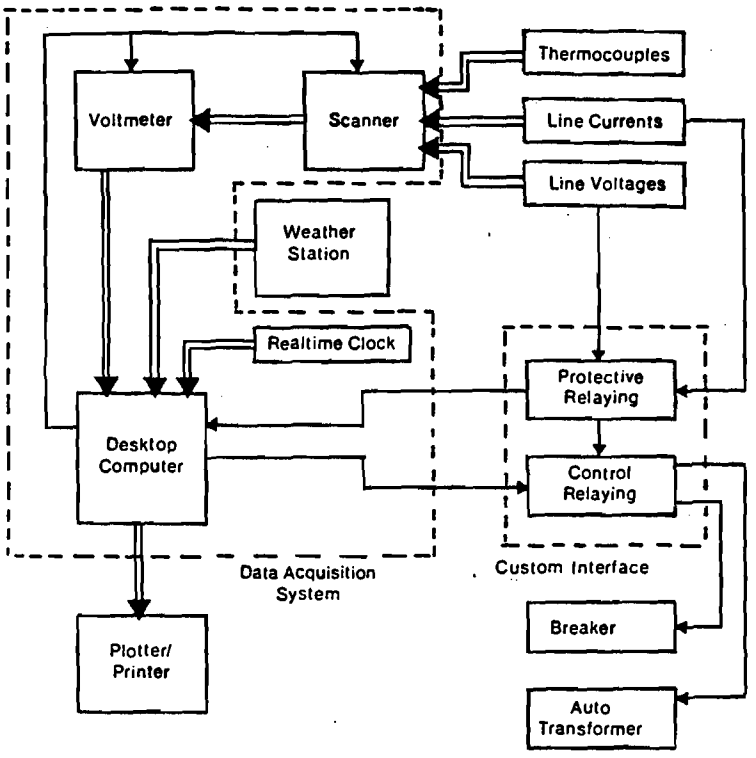

Figure 10. Block Diagram of Data Acquisition and Control System at Test Span

The current loading of the line was controlled by the data acquisition system. Sinusoidal, ramp, step and second order current curves could be impressed on the line. The motor driven variac was adjusted continuously to maintain the desired load cycle. Trip conditions such as a maximum line temperature or current could be set. The data collected using the data acquisition system included line current, line temperatures, wind speed, wind direction and ambient temperature. The data was stored digitally on a cassette tape. The tape data was subsequently transferred to floppy disk and the time, weather data and line current were input to DYNAMP for comparison to the measured temperatures.

To minimize the effects of lightning and induced voltage, the test span was grounded to the midpoint of the loading current transformers on one end of the line. A number of 1 kV lightning arresters were tied to ground at the other end of the line. A static wire was installed above the test span to further enhance the protection of instrumentation attached to the conductor. All thermocouples and signal leads were provided with transient protection. The output signal from the weather station was transmitted to the data acquisition system via a fiber optic link. Despite these protective measures, lightning damage still occurred occasionally to various parts of the measuring system.

The test system was originally built in 1981 and it was originally designed for a two-year test program. The test span was operated with a Linnet conductor from August, 1982 to October, 1985. In the fall of 1984 the EPRI Conductor Temperature Research Project was initiated and the existing facility was upgraded. The lightning protection system was reviewed resulting in the following changes. A fiber optic link was installed to the weather station and the thermocouple shielding was made continuous from the point of conductor attachment to the entry of the data acquisition system. Additional ground rods were driven to provide a more substantial ground field. Also, software modifications were written to allow the polling of the weather station to collect data. Additional software allowed transfer of data from the HP cassettes to floppy disks.

The Curlew conductor was installed on the span in November, 1985. Additional guying was added to support the heavier conductor. The Curlew conductor was used until October, 1986 when the experimental verification portion of the project was completed.

KANSAS GAS & ELECTRIC FIELD SITE

One of the goals of the research project was to verify the accuracy of DYNAMP using data collected at a field site. Unfortunately, no existing facility was found that could be economically converted for use as a second instrumented test span. To remove the obstacle, a commercially available on-line monitor was purchased and used to provide line temperature data on a set of KG&E existing operating lines.

Kansas Gas and Electric (KG&E) under a co-funding agreement with Kansas Electric Utilities Research Program (KEURP) and EPRI agreed to be the host utility for collection of line temperature data. The alternate site study was a cooperative effort between KG&E, the Center for Energy Studies at Wichita State University (WSU), the Kansas Technical Institute (KTI), Georgia Power Company and the Georgia Institute of Technology. WSU was the main contractor in charge of overall coordination of the project. KTI was a subcontractor to WSU and they were responsible for the design, construction and operation of the data recording system. KG&E provided facilities and engineering assistance. Georgia Power provided additional equipment and assistance in experiment design of the test apparatus.

Four conductors were selected for instrumentation with both the on-line monitor and with a weather station located at line height within twenty feet of the conductor. The experiments were conducted at two sites, the KG&E Gordon Evans generating station and the KG&E Weaver substation. Gordon Evans is approximately six miles northwest of Wichita and the Weaver substation is located about eight miles east of Wichita.

The first series of tests were performed at the Gordon Evans site between July 21 and August 1, 1986. The next series of tests were performed at the Weaver Substation between September 15 and September 25, 1986. The conductors involved in the test program are described in Table 5.

Table 5 KG&E Field Site Conductor Characteristics

SUBSTATION	CONDUCTOR	TYPE	STRANDING	AREA	DIAMETER	VOLTAGE
Gordon Evans	Flamingo	ACSR	24/7	666 kcmil	1.000 in	138 kV
Gordon Evans	Drake	ACSR	26/7	795 kcmil	1.108 in	138 kV
Weaver	Hawk	ACSR	26/7	477 kcmil	0.858 in	69 kV
Weaver	Rail	ACSR	45/7	954 kcmil	1.165 in	138 kV

The data recording equipment was designed, constructed and operated by KTI. A block diagram of the recording system is shown in Figure 11. The wind speed, wind direction and air temperature sensors were mounted near the conductor on a wood pole which was installed by KG&E line crews. The wind speed sensor was a cup anemometer manufactured by Maximum, Inc. which has a sine wave output with the output frequency proportional to wind speed. The pulse accumulator counts the anemometer output and produces a pulse for each 1/60 mile of wind travel. Therefore, the number of output pulses in a minute is equal to wind speed in mi/hr. The wind direction sensor generated an output of 0-5 V representing 0 to 360 degrees measured clockwise from north. A zero volt output represented a wind direction of magnetic north.

The sensors described above were not used during the measurements on the Flamingo conductor. A WVA320 combination hot wire anemometer and wind direction sensor which had an analog voltage output directly proportional to wind speed was used for the first week. However, it failed as a result of a lightning strike after the first conductor measurements were complete.

All air temperatures were obtained from the National Weather Service (NWS). Hourly readings of air temperature were obtained and a linear interpolation was used to obtain values between the hourly readings. The NWS air temperature sensor is located at the Wichita airport which is just southwest of the city.

Current transformers used to measure line current were already in place at the substations. Connections to these sensors were provided by KG&E personnel.

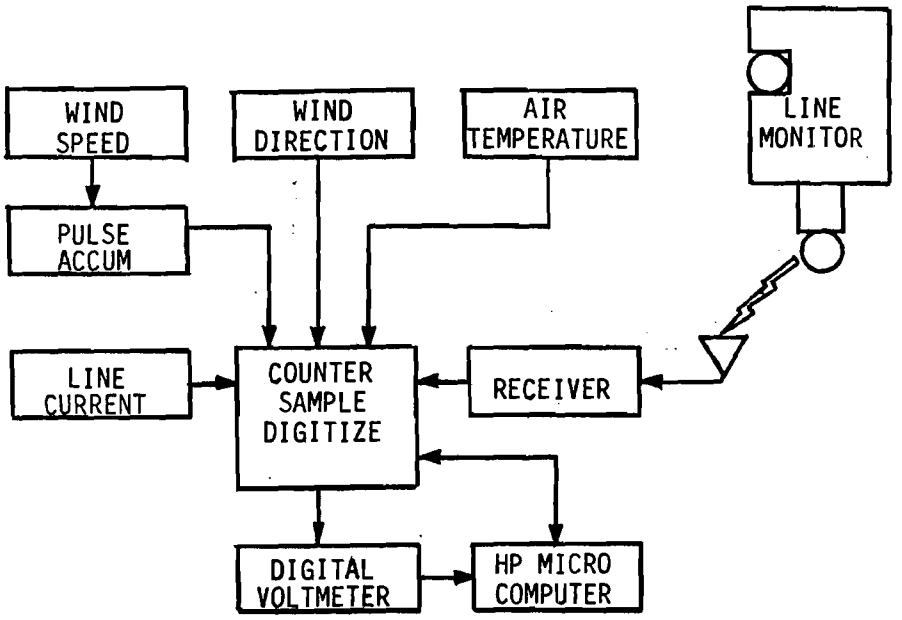

Figure 11. Block Diagram of Data Acquisition and Control System at Test Span

Line temperature was measured with a line monitor placed on the energized conductor. The calibration of this device was checked on the Georgia Power Test Span before and after use on the KG&E system. More detailed information on the calibration check of this device is presented in Section 9. The monitor clamps onto the conductor and a temperature sensor mounted in the jaws contacts the surface of the conductor. Power to operate the monitor is drawn from the transmission line using a current transformer. Therefore, the line must be energized and the conductor current must be at least 150 amperes to have sufficient power to record conductor temperature. A line outage was usually arranged when the monitor was installed. However, during one of the experiments, it was not possible to obtain an outage and the monitor was installed on an energized 138 kV line using a hot stick which is supplied with the instrument. The installation was completed without incident by a KG&E crew. A transmitter in the monitor sends a radio signal to a receiver which records a voltage proportional to the line temperature.

Some operating difficulties were encountered when the monitor was installed on the Hawk conductor at the Weaver substation. Random readings or no readings were being received from the monitor requiring that the device be returned to the manufacturer. The manufacturer was unable to uncover any problems with the device and when the monitor was re-installed, temperature readings were again obtained.

Signals from the various sensors were delivered to a custom-built board which contained a number of switching relays and a counter. The input from each sensor was connected to a relay, except for the pulse producing output of the anemometer which was connected to the counter. The relays were sequentially connected to the digital voltmeter. The digital voltmeter was a Fluke 8840A model and its output was connected to one of the computer input ports.

An HP integral personal computer was connected to the customer board through its RS-232 port. The computer, custom board, digital voltmeter and receiver were located in an air conditioned trailer supplied by KG&E. The trailer environment protected the instruments and also provided a comfortable place for working on the software and hardware and monitoring the experiment operation.The computer controlled the relay switching, recorded values from the voltmeter and it read the wind speed counts from the custom board. The computer clock was used to time the experiment. Every 5 minutes, readings of line current and line temperature were taken by closing the appropriate relay briefly and recording the digital voltmeter output. Because wind direction is highly variable, a single reading every five minutes was not taken. Instead, wind direction was sampled every two seconds and an average value over the five minute period was recorded. Also, at the end of each five minute period, the wind speed counter output was read and recorded. During the first week, when the hot wire anemometer was producing an analog signal proportional to wind speed, the wind speed was also sampled every two seconds and subsequently averaged for the five minute period before being recorded. The data acquisition system samples the clock reading and performs the sampling, averaging and recording. The data was recorded on the HP floppy disk. After each experiment was conducted, the data was transferred for further processing to a floppy disk compatible with an IBM PC.

PACIFIC GAS & ELECTRIC WIND TUNNEL

Pacific Gas & Electric used a wind tunnel to verify DYNAMP predicted conductor temperatures. One ACSR conductor and one AAC conductor were placed in the wind tunnel and thermocouples monitored the temperature as the wind velocity, wind angle and conductor current were varied. DYNAMP was then run for the given test conditions and the predicted temperatures were compared with the measured values. Since the tests were conducted in a wind tunnel where the conditions could be carefully controlled, the variations in weather parameters usually experienced in outdoor tests were not present.

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SECTION 6

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COMPARISON OF PROGRAM RESULTS WITH MEASURED CONDUCTOR TEMPERATURES

GEORGIA POWER TEST SPAN

The temperatures predicted by DYNAMP have been carefully compared with the temperatures measured on the outdoor test span over a period of two and one half years. Initially a Linnet ACSR conductor (26/7, 336 kcmil) was used and it remained in place for approximately one month during the initial stages of the contract. This one month period of data was supplemented by data collected during an 18 month period proceeding the contract.

The Linnet conductor was removed and replaced with a Curlew ACSR conductor (54/7, 1033 kcmil) and it remained on the test span throughout the duration of the project. Over 27,000 separate sets of weather and current data were collected and used as input condition to DYNAMP. These data were collected on five minute intervals over a period of two and one half years. These data represent nearly 94 days of continuous operation of the line and weather station. All data was statistically analyzed to determine the accuracy of the program and the results of the statistical analysis is discussed in the next section.

In general, DYNAMP is capable of predicting the conductor temperature to within $\pm$ 10^{o}C for temperatures up to 125^{o}C. The program is known to predict the conductor temperature more accurately under certain weather conditions (See the discussion on Critical Span Analysis, Section 8). The program accuracy is known to decrease for the following conditions:

1. Wind velocities that are close to zero.
2. Wind directions that are nearly down the axis of the conductor.
3. Currents and weather conditions that produce conductor temperatures in excess of 150^{o}C.
4. Periods of rainfall.
5. Weather conditions for the initial set of input parameters which are drastically different from the conditions that exist prior to the time the first set of data is recorded.

The decrease in program accuracy as the wind velocity decreases to zero and as the wind blows down the conductor axis is a result of increasing temperature sensitivity to these two weather conditions. This same phenomena also makes the measurement of a conductor temperature with a line monitor more subjected to error when the wind velocity is low and down the conductor axis.

While normal operating temperatures rarely exceed 125°C, even under emergency conditions, the program accuracy was checked under conditions which lead to temperatures in excess of 200°C. The results showed that DYNAMP was able to predict conductor temperatures to within ± 10°C at temperatures up to 125°C, but its accuracy decreased at higher temperatures. In general, the program averaged within 20°C for temperatures up to 225°C, but there were conditions (usually low wind velocities) where the program errors exceeded 20°C for brief periods of time.

The heat transfer model used to formulate DYNAMP does not consider the evaporative cooling that occurs during periods of rain. Since the evaporation of moisture on the surface of a conductor represents a significant cooling effect, the program will over-predict the conductor temperature during periods of rain. This trend is not considered to be a serious weakness of the program, because the predicted temperature is always conservative when the conductor is wet. However, the user should realize that there is considerable spare thermal capacity beyond the capacity predicted by DYNAMP whenever rainfall occurs at the location of the conductor.

The initial conductor temperature predicted by DYNAMP is a result of a steady-state energy balance on the conductor assuming that the first set of weather data does not vary with time. Mathematically this assumption is necessary to calculate an initial condition for the differential equation (Eq. 30). When the first set of weather conditions is very close to the weather conditions that preceded it, the predicted initial temperatures are very accurate. However, occasionally the first set of weather conditions is different from the previous data sets and in these instances, the program accuracy is poor until sufficient weather data has been reported which truly represents the average conditions in the vicinity of the line. This behavior of the program should not be considered a serious disadvantage, because the program must be started only once. Once the program has

been initiated and sufficient weather data has been accumulated, the starting errors, if they exist, will disappear.

The next few pages shows several selected comparisons of measured line temperatures and DYNAMP's predicted temperatures. Each curve has been selected to illustrate a particular point. All are displayed in a similar fashion with the wind conditions shown in the lower curves and the current, air temperature and conductor temperatures in the upper curves for the identical time period. The lower curves show a solid line representing the wind velocity in miles per hour and the wind direction data is plotted between 0 and 90^{o} where flow perpendicular to the conductor is plotted as 90^{o}. The upper curves show DYNAMP's temperature prediction as a solid line and the average thermocouple readings are illustrated by the square data points. The upper curves also include the measured air temperature and conductor current over the interval of the test.

Figure 12 for data collected on October 15, 1986 shows typical weather and current variation and the corresponding measured and predicted line temperatures. Differences between DYNAMP's predicted temperatures and the measured line temperatures average less than about 5°C over the 14 hours that data were collected. The data for October 20th shown in Figure 13 was collected during a period of much higher current and during that period the conductor temperature exceeded 125°C. Even at these high temperatures the trends predicted by DYNAMP remained excellent.

The data in Figs. 14 and 15 give an indication of the relatively large errors that can result when the wind velocity decrease to zero and the wind direction is down the axis of the conductor. Figure 14 for conditions on October 21 shows expected accuracy except for two brief periods. Around midnight (between 0:00 and 1:00 am) the wind was very calm and the program predicted temperatures that were at times both high and low of the measured values. As the wind velocity began to increase after 1:00 am, the usual accuracy of the program returned and it remained excellent with the exception of one brief period at approximately noon. At that time the wind was blowing down the axis of the conductor (wind angle = 0) and the program briefly predicted a temperature that was about 30°C higher than the measured temperature. Once the wind direction changed and the wind angle increased, the program accuracy returned.

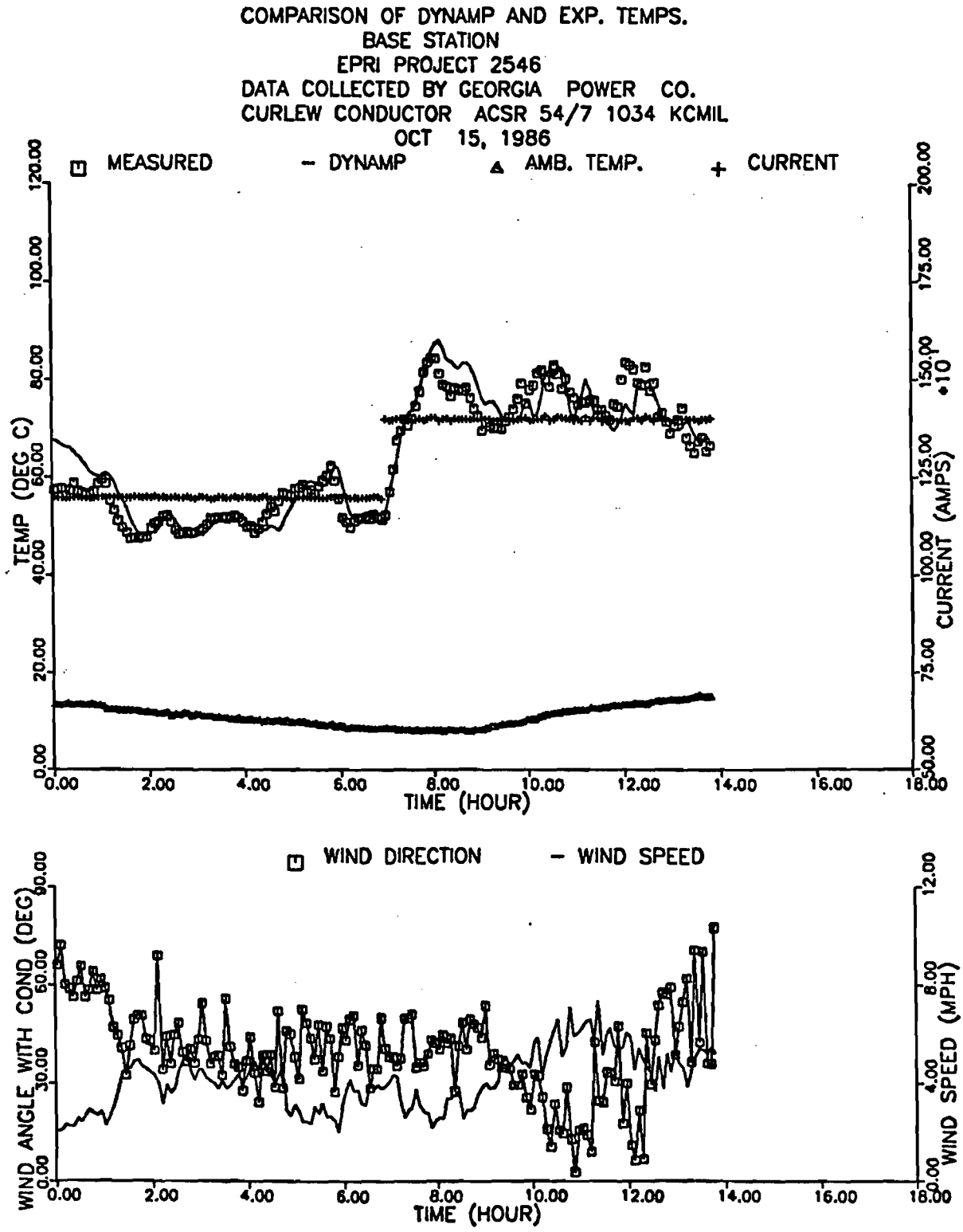

Figure 12. Measured and Predicted Conductor Temperatures for October 15, 1986

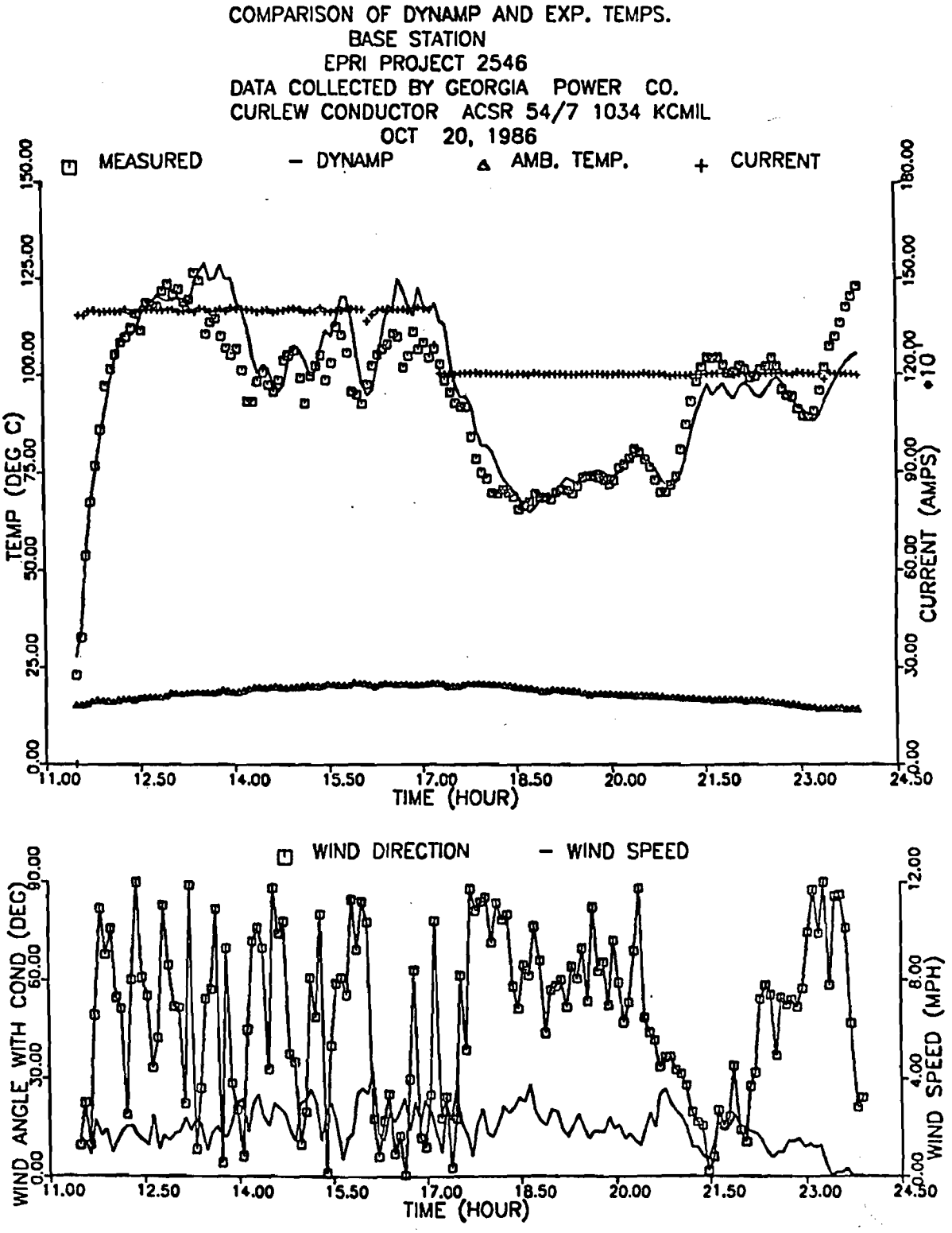

Figure 13. Measured and Predicted Conductor Temperatures for October 20, 1986

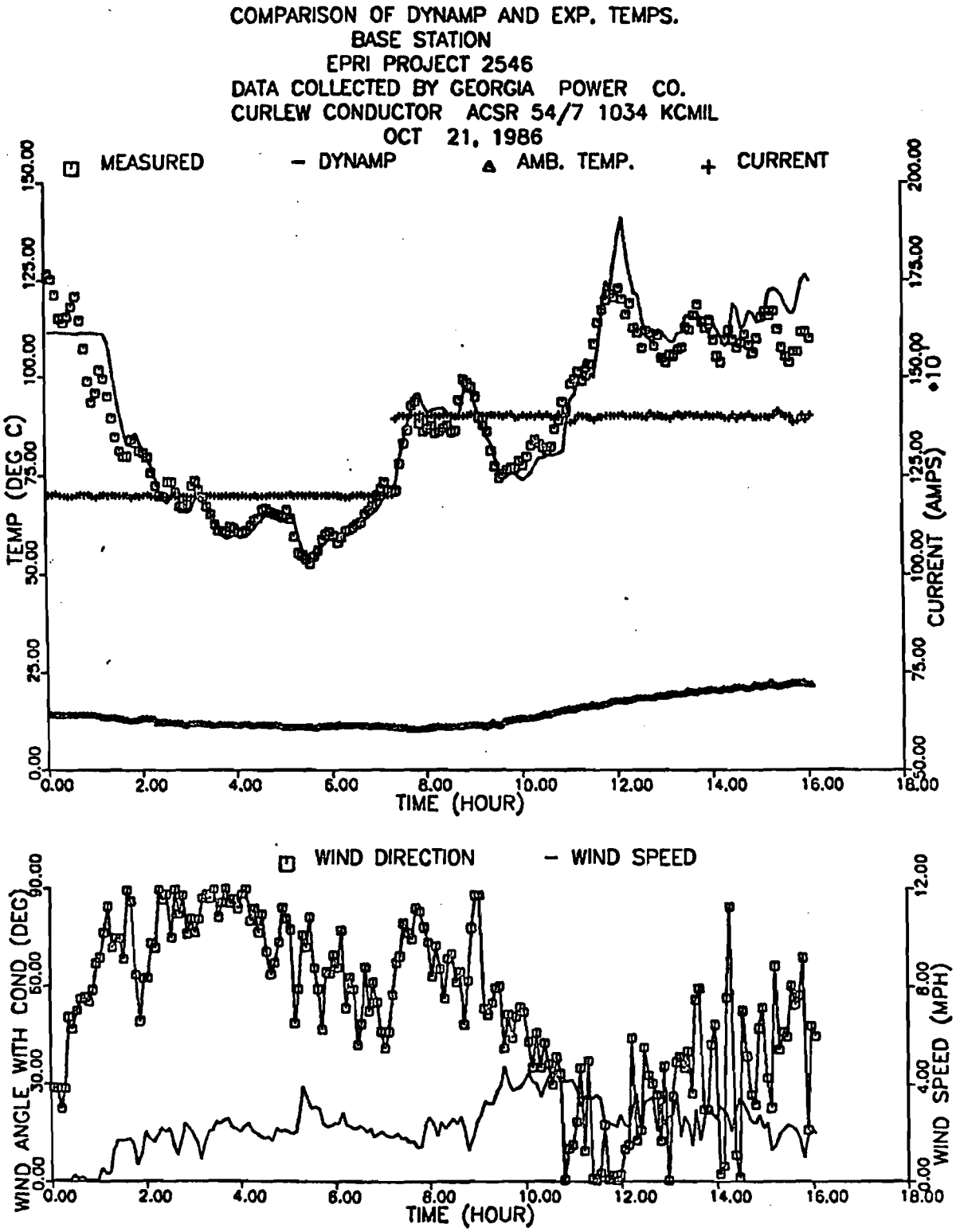

Figure 14. Measured and Predicted Conductor Temperatures for October 21, 1986

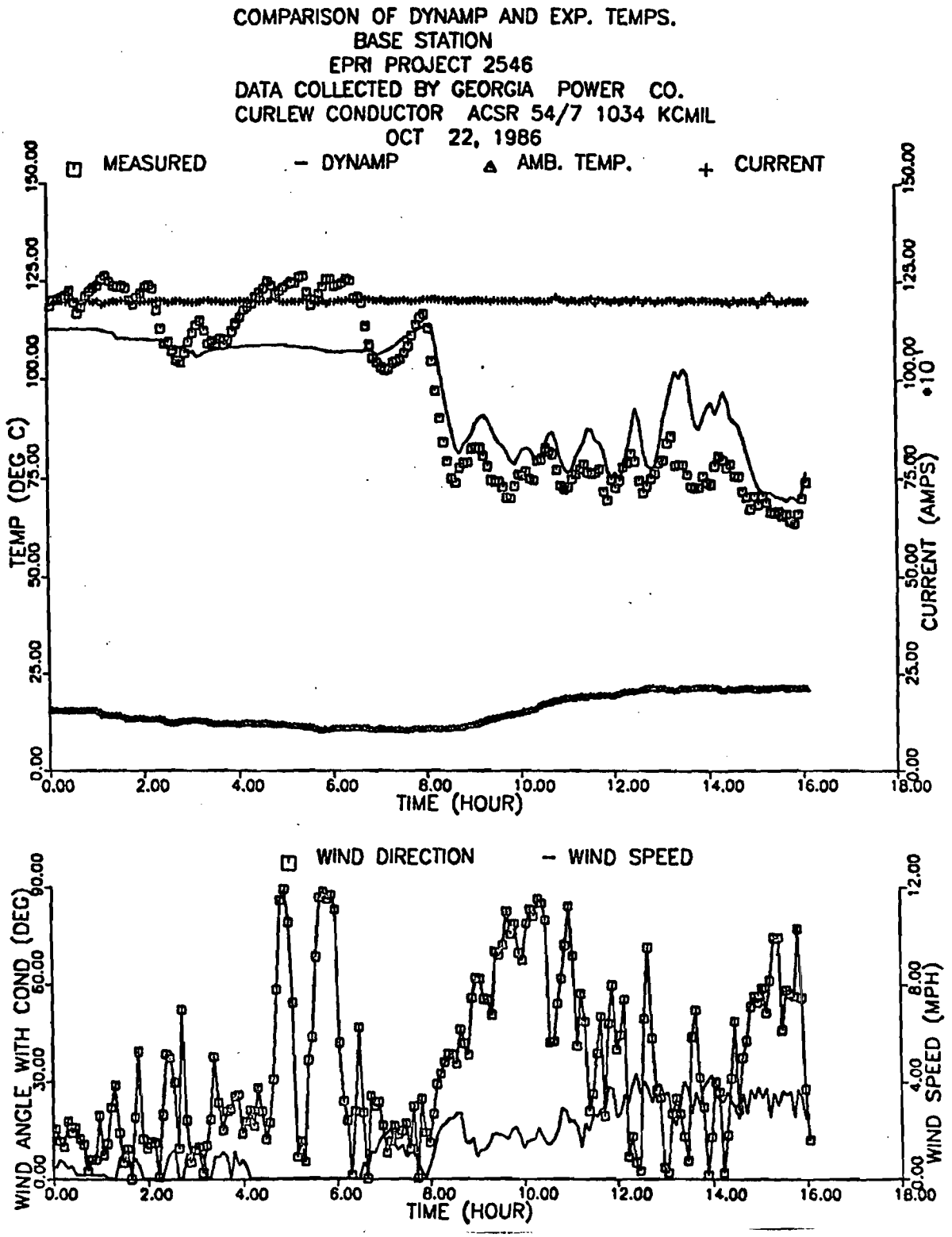

Figure 15. Measured and Predicted Conductor Temperatures for October 22, 1986

The data in Fig. 15 for October 22, 1986 show more sustained errors as a result of much longer periods when the weather station was indicating no wind was present at the conductor location. The weather station reported practically no wind from midnight until slightly after 6:00 am. Program errors during that same period averaged about 20°C.

Figure 16 shows the expected predicted temperatures within ± 10°C of the measured temperature even when the conductor temperature exceeded 130°C for a brief period of time. During the sixteen hour period that data was collected for Fig. 16, the wind direction was highly variable and unpredictable, but the wind direction did not fall along the conductor axis and the velocity did not drop below two mph. As a consequence the program accuracy remained good throughout the test period.

Figure 17 illustrates two points. First, the program is capable of accurately predicting the temperature during large changes in conductor current. Between 8:00 am and 9:00 am the current was reduced sharply from 1200 amps to zero and then returned to 1200 amps in a step fashion. Even under this rapid change in current, the program maintained reasonable accuracy. Figure 17 also indicates the rather large conservative errors the program can make during periods of rain. Between 2:00 pm and 5:00 pm, rain occurred at the test site and the measured conductor temperature dropped to a value close to that of the air temperature. Since the program does not consider the cooling effects of rain, it continued to predict a temperature which assumes no evaporative cooling. During this period the program over-predicted the temperature by as much as 40°C. The period of rainfall can be easily identified by noting the change in weather conditions that accompany the rain. The wind velocity increased during the rainfall period and the air temperature dropped during the same time.

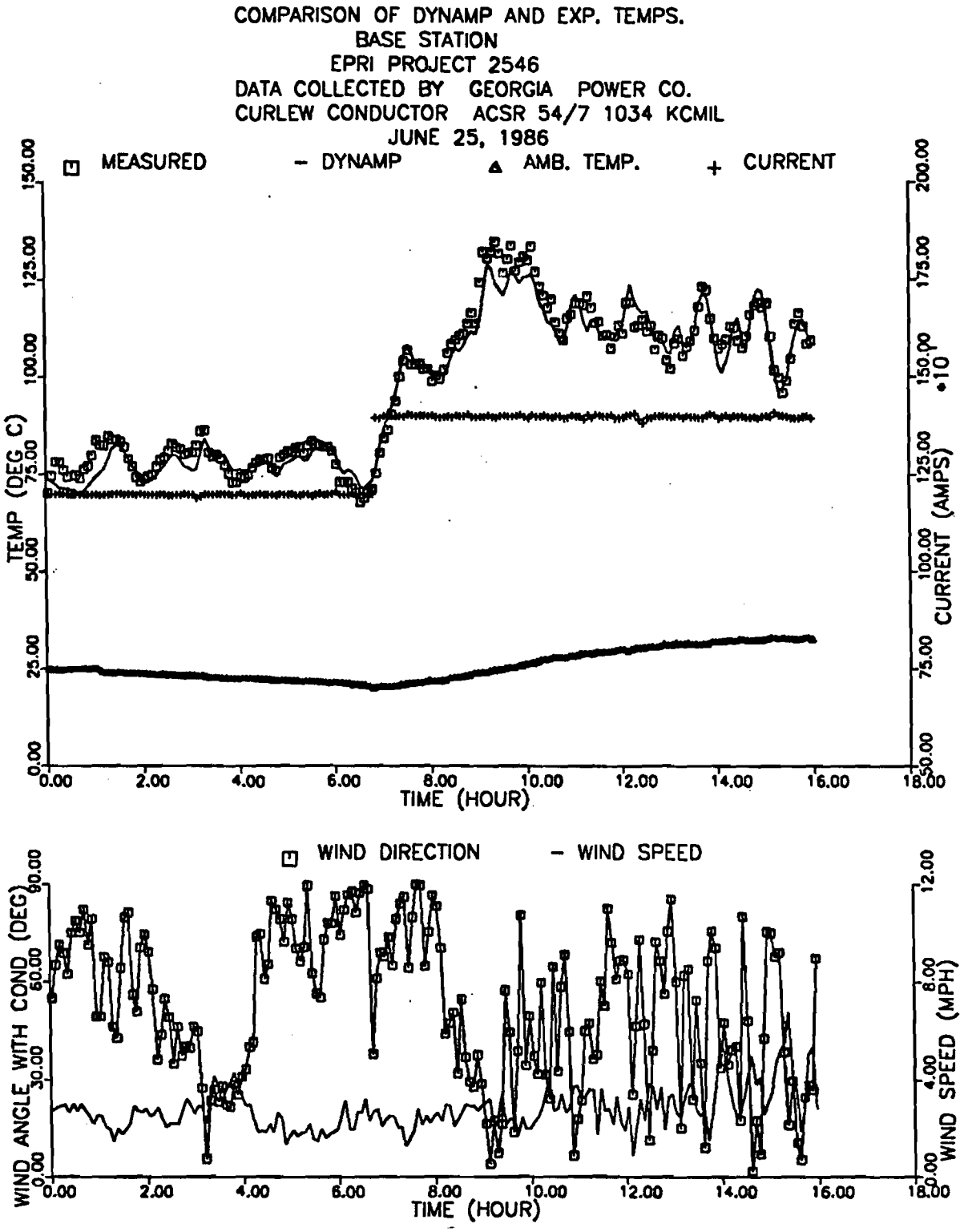

Figure 16. Measured and Predicted Conductor Temperatures Showing Excellent Accuracy for Conductor Temperatures in Excess of 130°C

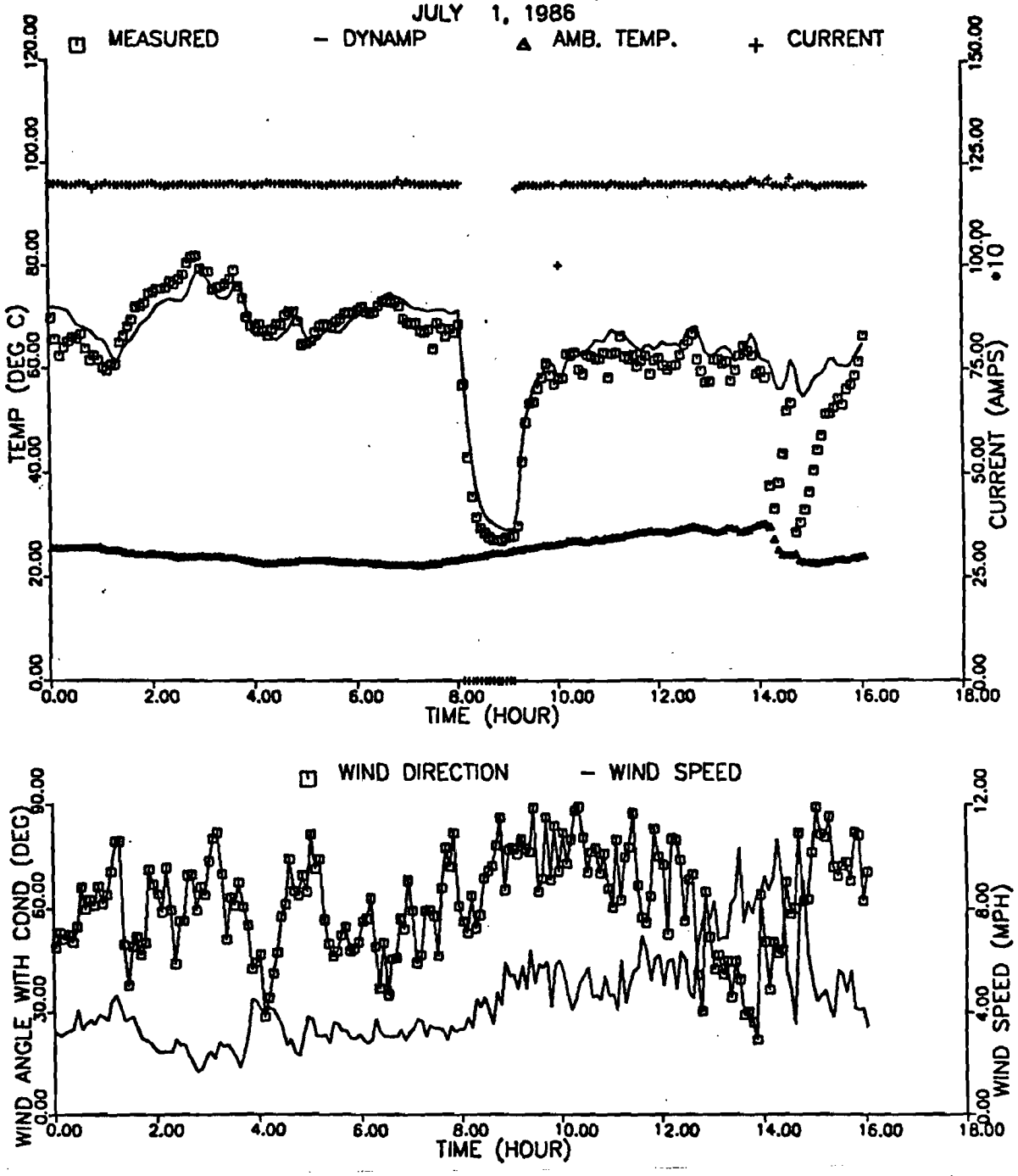

Figure 17. Measured and Predicted Conductor Temperatures Showing Errors which Result from Rainfall Between 2 and 5 pm

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SECTION 7

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STATISTICAL ANALYSIS OF PROGRAM RESULTS

During the two year period in which the test span was operated for this project, the Curlew conductor was in place for about 15 months. During that time over 26,400 data points of weather conditions, current and conductor temperature were collected and recorded on diskette. This number represents nearly 92 days of continual operation. All of these data points have been analyzed with DYNAMP and a statistical analysis of the program accuracy has been performed.

The result of the statistical analysis is shown in Tables 6 through 8. These tables include a total population of 24,700 data points out of the 26,400 points collected. The difference in these two numbers represents the data collected during periods of rain and the first few minutes at the beginning of each new collection period. At both of these times DYNAMP is known to be inaccurate, because it does not account for the evaporative cooling that occurs during rainfall and it is not able to predict the real-time temperature when it is given only a single weather data point at the beginning of a run. Therefore, these points were removed from the statistical package so that a true picture of the program accuracy would emerge.

The data in Table 6 shows the errors that resulted with DYNAMP for the total population of 24,700 data points collected over the 15 month period the test span was in operation with the Curlew conductor. The errors which appear in the table are defined as the difference between DYNAMP's predicted temperature and the average reading of the 16 thermocouples that were mounted on the line. DYNAMP's predicted temperature was within $\pm$ 0.5°C for 2817 of the data points or 11.4% of the time. Over half of the data points collected resulted in an error of $\pm$ 2°C and greater than 90% of the data points were within $\pm$ 8°C of the correct temperature.

BASE STATION

TEMPERATURE RANK PERCENTAGES

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
0	2817	11.4	11.4	53.7	21.3	5.7	2.6	1.5	0.00	98.5
1	5423	22.0	33.4	54.5	21.2	5.7	2.7	2.2	0.00	97.8
2	4277	17.3	50.7	53.1	21.4	6.0	3.1	2.8	0.00	97.2
3	3123	12.6	63.3	52.1	22.6	6.0	3.4	4.1	0.00	95.9
4	2238	9.1	72.4	50.7	22.9	5.7	3.4	5.1	0.00	94.9
5	1628	6.6	79.0	48.8	23.3	5.4	3.2	5.3	0.00	94.7
6	1210	4.9	83.9	45.9	23.8	5.2	3.2	8.3	0.00	91.7
7	935	3.8	87.7	44.7	24.7	4.9	3.1	10.1	0.00	89.9
8	686	2.8	90.4	40.1	25.3	4.8	3.2	13.6	0.00	86.4
9	474	1.9	92.4	37.9	24.2	4.4	2.7	13.9	0.00	86.1
10	368	1.5	93.8	35.3	24.6	4.7	3.1	15.5	0.00	84.5
11	281	1.1	95.0	35.6	25.6	4.7	2.9	13.2	0.00	86.8
12	215	0.9	95.9	34.0	24.6	4.5	3.1	19.1	0.00	80.9
13	193	0.8	96.6	35.7	24.8	4.1	2.9	20.2	0.00	79.8
14	146	0.6	97.2	38.0	27.5	4.6	3.2	18.5	0.00	81.5
15	109	0.4	97.7	32.1	25.2	4.7	3.5	22.0	0.00	78.0
16	87	0.4	98.0	34.0	25.0	4.4	3.2	19.5	0.00	80.5
17	76	0.3	98.3	29.6	24.8	4.6	3.2	27.6	0.00	72.4
18	66	0.3	98.6	31.0	27.5	4.0	2.8	22.7	0.00	77.3
19	47	0.2	98.8	28.7	28.2	5.1	3.1	19.1	0.00	80.9
20	49	0.2	99.0	31.4	26.8	5.2	3.5	10.2	0.00	89.8
21	46	0.2	99.2	32.7	26.5	5.6	3.5	10.9	0.00	89.1
22	28	0.1	99.3	30.4	27.7	5.4	3.0	3.6	0.00	96.4
23	23	0.1	99.4	28.1	23.9	4.8	3.6	8.7	0.00	91.3
24	27	0.1	99.5	24.5	22.4	5.7	3.6	11.1	0.00	88.9
25	15	0.1	99.5	42.1	26.4	4.3	2.3	20.0	0.00	80.0
26	8	0.0	99.6	24.4	26.3	5.0	4.5	25.0	0.00	75.0
27	10	0.0	99.6	33.5	30.2	3.7	3.0	40.0	0.00	60.0
28	8	0.0	99.6	45.0	25.9	4.1	2.9	12.5	0.00	87.5
29	7	0.0	99.7	31.3	31.5	4.4	2.1	14.3	0.00	85.7
30	5	0.0	99.7	16.8	18.1	5.6	1.3	0.0	0.00	100.0
31	10	0.0	99.7	26.4	26.3	5.1	1.6	10.0	0.00	90.0
32	9	0.0	99.8	17.5	26.7	5.9	2.1	33.3	0.00	66.7
33	12	0.0	99.8	35.1	29.8	4.7	2.0	8.3	0.00	91.7
34	7	0.0	99.9	22.4	20.5	4.8	1.6	28.6	0.00	71.4
35	3	0.0	99.9	32.3	36.1	6.3	1.7	0.0	0.00	100.0
36	6	0.0	99.9	14.5	14.4	4.2	1.5	50.0	0.00	50.0
37	2	0.0	99.9	38.0	1.4	5.7	3.1	0.0	0.00	100.0
38	4	0.0	99.9	26.2	4.6	4.0	1.7	0.0	0.00	100.0
39	6	0.0	99.9	24.0	11.0	4.3	1.4	16.7	0.00	83.3
41	1	0.0	99.9	13.0	0.0	5.3	0.0	0.0	0.00	100.0
42	1	0.0	99.9	19.0	0.0	2.3	0.0	0.0	0.00	100.0
43	1	0.0	99.9	69.1	0.0	2.8	0.0	0.0	0.00	100.0
44	1	0.0	100.0	1.0	0.0	5.5	0.0	0.0	0.00	100.0
50	12	0.0	100.0	36.1	27.5	4.3	3.2	25.0	0.00	75.0

Table 6. Statistical Analysis of DYNAMP's Predicted Temperatures for a Total of 24,700 Data Points

DYNAMP PREDICTS EXACTLY AS MEASURED FOR 11.4 %

DYNAMP PREDICTS HIGHER THAN MEASURED FOR 61.5 %

DYNAMP PREDICTS LOWER THAN MEASURED FOR 27.1 %

MEAN TEMPERATURE ERROR IN DEGREES C (DYNAMP > MEASURED) : 4.5 +/- 4.5

MEAN TEMPERATURE ERROR IN DEGREES C (DYNAMP < MEASURED) : 3.6 +/- 3.7

NUMBER OF DATA POINTS (DYNAMP > MEASURED) : 15191

NUMBER OF DATA POINTS (DYNAMP < MEASURED) : 6692

NUMBER OF DATA POINTS (DYNAMP = MEASURED) : 2817

TOTAL DATA POINTS ANALYZED : 24700

Table 6 (Continued)

Over 61% of the data resulted in DYNAMP predicting a temperature greater than the measured conductor temperature. Only 27% of the predicted temperatures were less than the measured value. This behavior of over-predicting the conductor temperature was intentional, because the program was designed to be on the conservative side.

The data in Tables 7 and 8 contain the same data as shown in Table 6 except that Table 7 contains only those points for which DYNAMP over-predicted the temperature and Table 8 shows only those cases where DYNAMP calculates a temperature lower than the measured value. These values show that more accurate predictions occur at higher wind velocities (see column labeled AV.SPEED) and when the wind is more in cross-flow than parallel flow (see column labeled AV.ANGLE).

BASE STATION

T E M P E R A T U R E R A N K P E R C E N T A G E S

DYNAMP PREDICTS HIGHER THAN MEASURED

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,=)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV FREE	REGIME(%) INTP	FORCED
1	3314	13.4	34.0	55.7	20.7	6.1	2.8	1.7	0.00	98.3
2	2856	11.6	49.9	54.6	20.9	6.8	3.2	1.9	0.00	98.1
3	2205	8.9	62.2	54.1	21.8	6.9	3.4	2.4	0.00	97.6
4	1643	6.7	71.3	52.8	22.2	6.5	3.4	3.2	0.00	96.8
5	1216	4.9	78.0	50.9	22.7	6.1	3.3	3.1	0.00	96.9
6	913	3.7	83.1	47.9	23.4	5.8	3.2	3.9	0.00	96.1
7	700	2.8	87.0	46.8	24.8	5.5	3.1	5.1	0.00	94.9
8	523	2.1	89.9	41.8	24.9	5.3	3.2	7.3	0.00	92.7
9	345	1.4	91.8	40.7	23.7	5.0	2.8	5.5	0.00	94.5
10	268	1.1	93.3	37.5	25.0	5.3	3.2	8.6	0.00	91.4
11	212	0.9	94.5	36.7	26.0	5.4	2.9	5.7	0.00	94.3
12	163	0.7	95.4	34.5	23.9	5.2	3.1	10.4	0.00	89.6
13	144	0.6	96.2	35.4	24.0	4.9	2.9	11.8	0.00	88.2
14	109	0.4	96.8	36.3	26.8	5.5	3.1	8.3	0.00	91.7
15	87	0.4	97.3	30.5	24.4	5.4	3.5	12.6	0.00	87.4
16	65	0.3	97.6	34.0	24.8	5.3	3.1	6.2	0.00	93.8
17	62	0.3	98.0	28.5	25.8	5.3	3.0	17.7	0.00	82.3
18	54	0.2	98.3	29.4	27.0	4.6	2.7	14.8	0.00	85.2
19	42	0.2	98.5	28.3	28.2	5.4	3.1	16.7	0.00	83.3
20	44	0.2	98.7	29.8	27.3	5.5	3.5	11.4	0.00	88.6
21	42	0.2	99.0	31.3	27.1	5.9	3.6	11.9	0.00	88.1
22	24	0.1	99.1	28.2	28.6	5.8	3.1	4.2	0.00	95.8
23	23	0.1	99.2	28.1	23.9	4.8	3.6	8.7	0.00	91.3
24	26	0.1	99.4	24.0	22.7	5.9	3.6	11.5	0.00	88.5
25	12	0.0	99.5	37.0	26.9	4.3	1.9	25.0	0.00	75.0
26	6	0.0	99.5	29.2	29.3	3.9	2.0	16.7	0.00	83.3
27	10	0.0	99.5	33.5	30.2	3.7	3.0	40.0	0.00	60.0
28	8	0.0	99.6	45.0	25.9	4.1	2.9	12.5	0.00	87.5
29	7	0.0	99.6	31.3	31.5	4.4	2.1	14.3	0.00	85.7
30	5	0.0	99.7	16.8	18.1	5.6	1.3	0.0	0.00	100.0
31	10	0.0	99.7	26.4	26.3	5.1	1.6	10.0	0.00	90.0
32	9	0.0	99.8	17.5	26.7	5.9	2.1	33.3	0.00	66.7
33	9	0.0	99.8	20.7	15.9	5.4	1.7	11.1	0.00	88.9
34	7	0.0	99.8	22.4	20.5	4.8	1.6	28.6	0.00	71.4
35	3	0.0	99.9	32.3	36.1	6.3	1.7	0.0	0.00	100.0
36	6	0.0	99.9	14.5	14.4	4.2	1.5	50.0	0.00	50.0
37	2	0.0	99.9	38.0	1.4	5.7	3.1	0.0	0.00	100.0
38	4	0.0	99.9	26.2	4.6	4.0	1.7	0.0	0.00	100.0
39	6	0.0	100.0	24.0	11.0	4.3	1.4	16.7	0.00	83.3
41	1	0.0	100.0	13.0	0.0	5.3	0.0	0.0	0.00	100.0
44	1	0.0	100.0	1.0	0.0	5.5	0.0	0.0	0.00	100.0
50	5	0.0	100.0	21.0	34.4	2.3	3.6	60.0	0.00	40.0

Table 7. Statistical Analysis of Data Points Where Predicted Temperature is Greater than Measured Values

BASE STATION

T E M P E R A T U R E R A N K P E R C E N T A G E S

DYNAMP PREDICTS LOWER THAN MEASURED

ERROR (C)	NO. PTS	PERCENT =	PERCENT < or =	AV ANGLE (DEG,-)	ANGLE ST DV	AV SPEED (FT/S)	SPEED ST DV	CONV REGIME(%) FREE	INTP	FORCED
1	2109	8.5	51.8	52.8	21.8	5.0	2.3	3.0	0.00	97.0
2	1421	5.8	66.7	50.0	22.1	4.4	2.2	4.8	0.00	95.2
3	918	3.7	76.4	47.0	23.7	3.9	2.1	8.0	0.00	92.0
4	595	2.4	82.7	44.8	23.6	3.6	2.1	10.3	0.00	89.7
5	412	1.7	87.0	42.7	24.0	3.5	1.9	11.9	0.00	88.1
6	297	1.2	90.1	39.7	24.1	3.4	2.4	21.9	0.00	78.1
7	235	1.0	92.6	38.6	23.2	3.2	2.4	24.7	0.00	75.3
8	163	0.7	94.3	34.8	25.6	2.9	2.3	33.7	0.00	66.3
9	129	0.5	95.7	30.3	24.0	2.8	1.7	36.4	0.00	63.6
10	100	0.4	96.7	29.4	22.7	3.1	2.0	34.0	0.00	66.0
11	69	0.3	97.4	32.5	24.4	2.4	1.4	36.2	0.00	63.8
12	52	0.2	98.0	32.4	27.1	2.4	2.0	46.2	0.00	53.8
13	49	0.2	98.5	36.8	27.2	2.0	1.5	44.9	0.00	55.1
14	37	0.1	98.9	43.0	29.5	1.8	1.6	48.6	0.00	51.4
15	22	0.1	99.1	38.3	27.9	2.0	1.6	59.1	0.00	40.9
16	22	0.1	99.3	34.0	26.2	1.6	1.6	59.1	0.00	40.9
17	14	0.1	99.5	34.3	19.9	1.2	1.4	71.4	0.00	28.6
18	12	0.0	99.6	37.9	29.9	1.3	1.3	58.3	0.00	41.7
19	5	0.0	99.7	31.7	30.9	2.6	1.6	40.0	0.00	60.0
20	5	0.0	99.7	45.5	18.0	2.5	1.1	0.0	0.00	100.0
21	4	0.0	99.8	47.0	14.3	2.6	0.7	0.0	0.00	100.0
22	4	0.0	99.8	44.1	17.8	3.0	0.4	0.0	0.00	100.0
24	1	0.0	99.8	37.0	0.0	1.8	0.0	0.0	0.00	100.0
25	3	0.0	99.9	62.7	11.0	4.0	4.0	0.0	0.00	100.0
26	2	0.0	99.9	10.1	2.8	8.1	9.8	50.0	0.00	50.0
33	3	0.0	99.9	78.3	11.2	2.5	0.5	0.0	0.00	100.0
42	1	0.0	99.9	19.0	0.0	2.3	0.0	0.0	0.00	100.0
43	1	0.0	99.9	69.1	0.0	2.8	0.0	0.0	0.00	100.0
50	7	0.0	100.0	46.8	16.7	5.7	2.2	0.0	0.00	100.0

Table 8. Statistical Analysis of Data Points Where Predicted Temperatures are Less than Measured Values

KANSAS GAS AND ELECTRIC FIELD SITE

The weather data and the conductor currents collected as part of the KEURP project were used to evaluate the accuracy of the line monitor and to compare the temperatures measured with the monitor to those values predicted by DYNAMP. Data was collected over a one month period for four different conductor sizes. At each site, the line monitor was installed on an energized line and a weather station was located in the immediate vicinity of the monitor. Since the transmission lines were energized, thermocouples could not be used to provide a base-line temperature against which the monitor or DYNAMP results could be compared. Results obtained on the Drake conductor on July 31, 1986 show some of the best temperature comparisons between the monitor and program (Figure 18). In general, the comparison was not as good as indicted in Figure 18 and the differences between predicted and measured temperatures were far greater than the data collected in Georgia. Weather conditions were somewhat different than experienced in Georgia because the Kansas wind velocity, in general, was much higher and fairly sustained. The data collected on September 24, 1986 on the Rail conductor produced very poor correlations as shown in Figure 19. Differences between the monitor temperature and the DYNAMP predicted temperature exceeded 10°C for substantial periods of time. Also between midnight and 4 am the monitor temperature was lower than the ambient temperature, raising serious doubt about the accuracy of the monitor during this period.

Analysis of the KG&E data is somewhat difficult since there is no measured conductor temperature against which to compare the monitor or DYNAMP results. This difficulty emphasizes the need to perform comprehensive testing such as was performed at the Georgia Power Test Span and in the PG&E wind tunnel. Only by calibrating a line monitor under expected field conditions can one be assured that it is measuring the conductor temperature accurately.

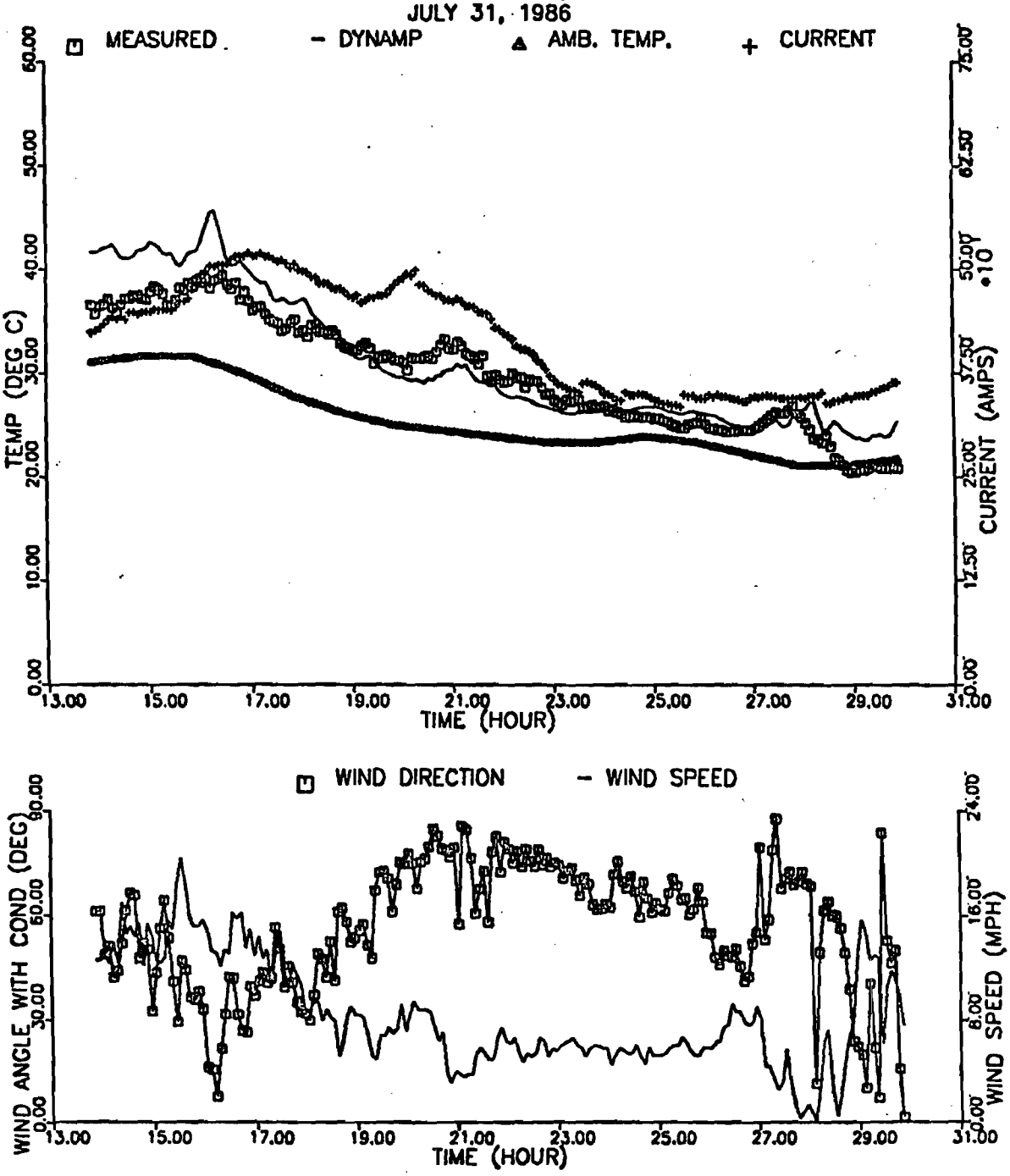

Figure 18. Comparison of DYNAMP and Line Monitor for KG&E Drake Conductor on July 31, 1986

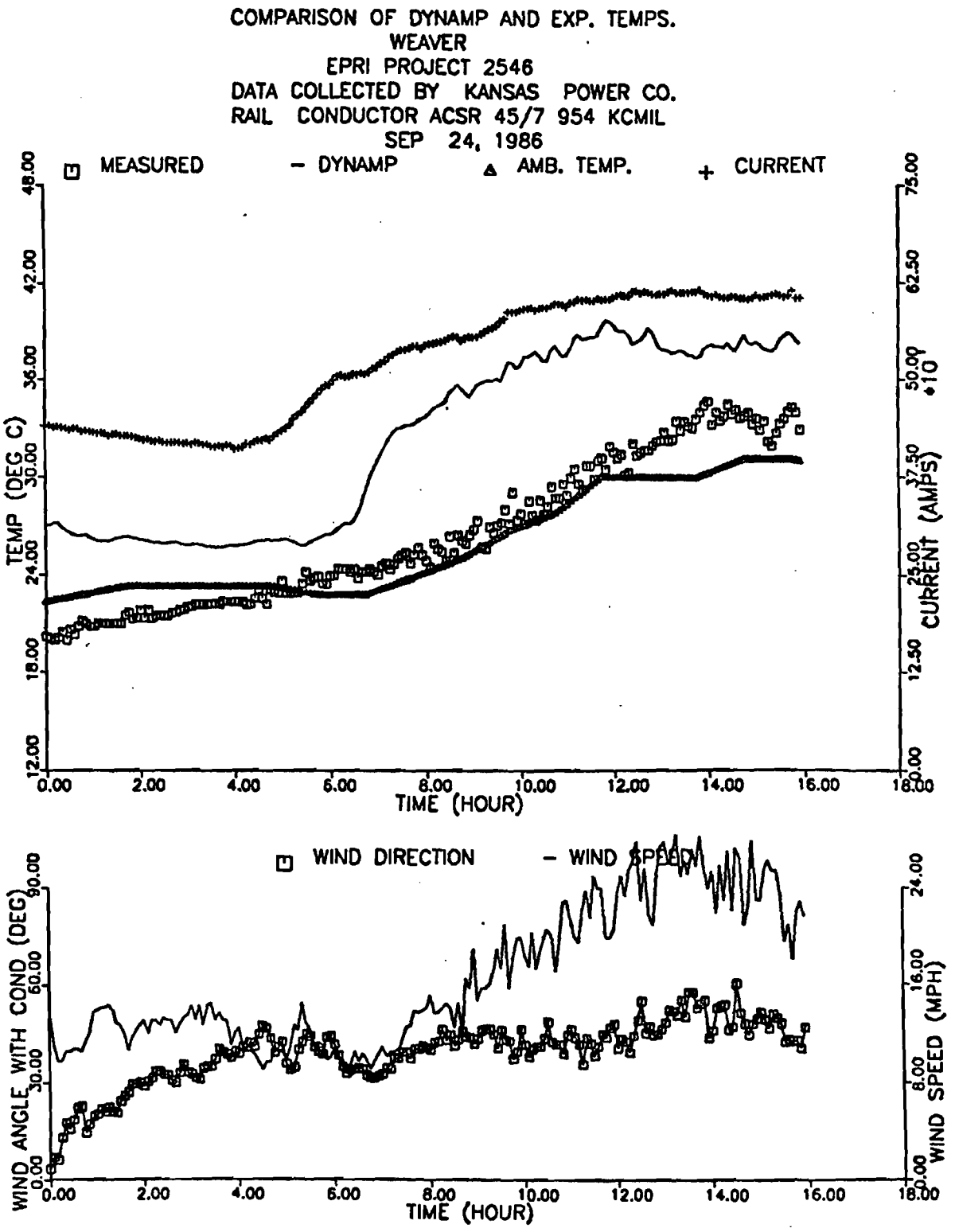

Figure 19. Comparison of DYNAMP and Line Monitor for KG&E Rail Conductor on September 24, 1986

PACIFIC GAS AND ELECTRIC WIND TUNNEL

Additional verification of the DYNAMP program was performed by the PG&E Department of Engineering Research in San Ramon, California in a specially designed wind tunnel. By accurately varying the weather parameters, a check of the DYNAMP program could be obtained under very controlled test conditions. Tests were obtained on both all aluminum and ACSR conductors and both the core and surface temperatures of the test conductor were measured. The DYNAMP predicted conductor temperatures consistently fell between the measured core and surface temperatures. This trend is expected because the DYNAMP program assumes that no radial temperature gradient exists in the conductor and it therefore predicts an average conductor temperature.

The transient response of DYNAMP was evaluated by subjecting a 1113 kcmil AAC Marigold conductor to a step current change from 300 to 1200 amperes. The conductor response and DYNAMP predictions are shown in Figure 20 for a perpendicular wind at 4.4 mph and an ambient temperature of 34.5°C. The DYNAMP prediction is consistently within a few degress of the measured core and surface conductor temperatures.

The same Marigold conductor was subjected to a series of six step changes in current over a period of two hours to evaluate the time response of the DYNAMP program and the results are plotted in Figure 21. The conductor was placed at a direction perpendicular to the wind at a velocity of 4.5 mph. The ambient temperature was 30.4°C. Again, the DYNAMP predicted temperatures are within a few degress of the measured surface and conductor temperatures.

The tests carried out in the PG&E wind tunnel verified the accuracy of DYNAMP for both steady-state and real time calculations under conditions that can be much more accurately and precisely controlled than outdoor tests. As a result, the comparison of predicted and measured temperatures showed much smaller differences than existed during outdoor tests where weather conditions, particularly wind speed and direction, cannot be regulated or controlled.

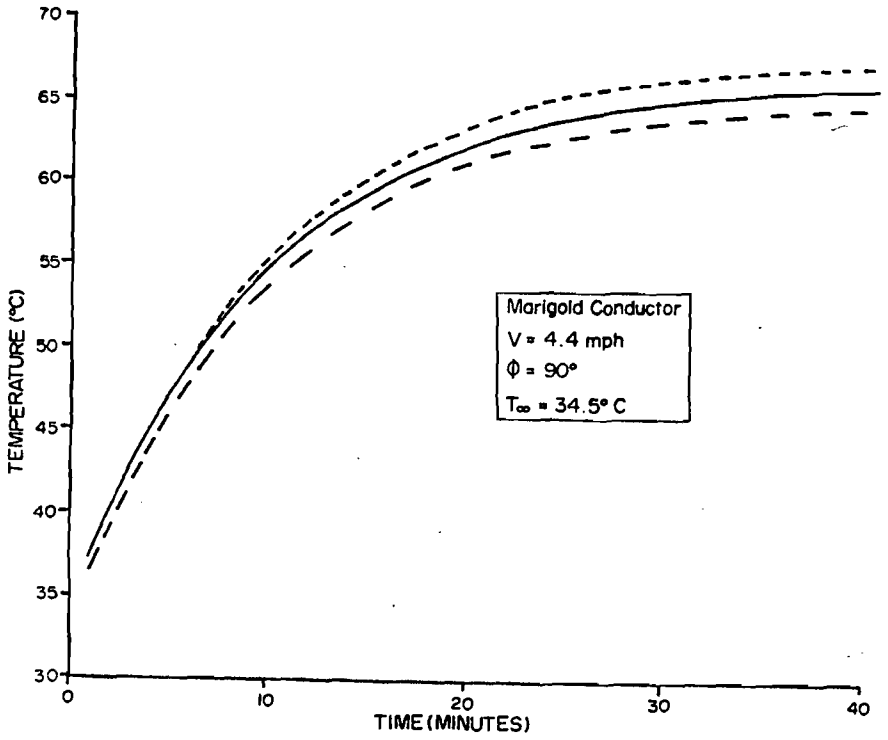

Figure 20. Comparison of DYNAMP and PG&E Wind Tunnel for Marigold Conductor AFter a Step Change from 300 to 1200 Amperes

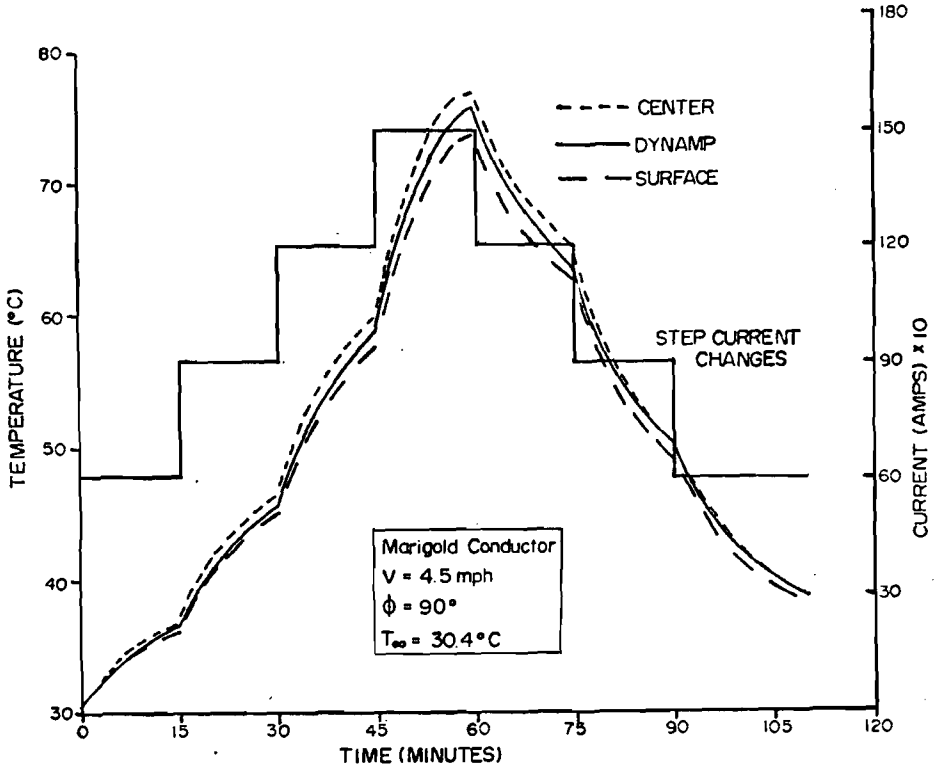

Figure 21. Comparison of DYNAMP and PG&E Wind Tunnel Data for Marigold Conductor after a Series of Seven Current Step Changes

DRAFT

SECTION 8

CRITICAL SPAN ANALYSIS

DRAFT

INTRODUCTION

The utility survey (See Section 2) revealed the fact that many utilities subscribe to the concept of a critical span. Most engineers define a critical span as one which operates at a temperature above the remaining spans in the transmission line and it therefore thermally limits the amount of power that can be delivered by the circuit. Regardless of whether a utility has decided to measure conductor temperatures with line monitors or predict them with a computer model based on measured weather conditions, the concept of a critical span will help reduce the capital investment necessary to institute a thermal line monitoring scheme. Therefore, the concept of a critical span is a desirable one, because it tends to simplify the complicated problem of predicting the real-time temperature of an entire transmission circuit. The critical span therefore represents a thermal chokepoint which limits the amount of power that can be delivered by the circuit. The concept of a critical span is a particularly attractive one to an operating engineer who has the responsibility of economically and safely operating a transmission network, because it theoretically identifies the thermal weak link in each transmission line. By loading the system on the basis of the limiting critical span, the complex job of making load flow decisions without exceeding sag or loss of strength limits becomes, at least in theory, a much less demanding task.

If the temperature of a line is to be measured by thermal line monitors, then the monitors can, theoretically, be located at the critical spans. Likewise, if the conductor temperatures are to be predicted by using a computer model coupled with weather data measured along the route, then the weather station can be located at the critical span. Regardless of which technique for predicting the conductor temperature is eventually selected, the concept of critical span will help minimize the equipment costs.

The wind velocity and direction near the conductor are known [20,21] to be two of the most significant parameters in regulating the conductor temperature. This fact suggests that any span along the route of the line which has a reduced wind velocity would be an obvious choice for a critical span. Lines that are routed through valleys, tall stands of trees or other areas where the wind is inhibited from circulating freely over the conductor would be prime candidates for a critical span. Furthermore, wind which blows down the axis of the conductor is much less effective in cooling the conductor than wind which blows across the conductor. Therefore spans which are oriented in a direction such that they are parallel to the predominant wind direction are also reasonable choices for critical spans.

While the concept of a critical span is quite simple, unfortunately it is difficult to put into practice. The temperature of an overhead conductor is a complex function of a wide variety of parameters including conductor size, current, electric resistance, weather conditions, line location and orientation, localized sheltering of the conductor and radiative properties of the surface of the conductor. Any computer model or line monitoring equipment must successfully account for all of these factors if they are expected to accurately predict the conductor temperature.

SENSITIVITY PARAMETERS

In order to predict the location of the critical span, one must know how sensitive the conductor temperature is to the numerous parameters which influence it. This requirement leads to the definition and derivation of sensitivity parameters which will help determine whether a critical span can be located with any accuracy and repeatability. Expressions for each of the sensitivity parameters are obtained by taking derivatives of temperature with respect to each of the independent variables that occur in Equation 6. Equation 6 shows that the conductor temperature is a complex function of many factors. Obviously not all of the parameters affect the conductor temperature equally. Some have a major impact on the conductor temperature while others have practically no influence. The derivative process produces the seven sensitivity parameters listed in Table 9. A detailed derivation of the sensitivity parameters is given in Reference [37].

The sensitivity parameters are convenient quantities which show how each variable influences the conductor temperature. Therefore, they will help to determine the location of critical spans. For example, the sensitivity parameter for wind velocity ($\partial T/\partial V$) quantifies changes in the conductor temperature with changes in the wind velocity. If the average value of $\partial T/\partial V$ is $-10^{o}C/(ft/sec)$ within a given range of operating conditions, then that conductor will experience a temperature decrease of $10^{o}C$ for a 1 ft/sec increase in wind velocity. Since wind velocities

Table 9. Sensitivity Parameters.

$$\frac{\partial T}{\partial V} = \frac{\pi D(T-T_\infty)\left[\frac{k}{\nu}10^{A}(a_1/Re_D+2a/Re_D\log_{10}Re_D)\right](1.194-\sin\omega-0.194\cos2\omega+0.368\sin2\omega)}{I^2\,\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh}$$

$$\frac{\partial T}{\partial \phi} = \frac{k\pi 10^{A}\,(T - T_\infty)(\cos\omega - 0.388\sin2\omega - 0.736\cos2\omega)}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh} \qquad \frac{\partial T}{\partial \epsilon} = \frac{\sigma\pi D(T^4 - T_\infty{}^4)}{I^2\partial R_{AC}/\partial T-4\epsilon\sigma\pi DT^3-\pi Dh}$$

$$\frac{\partial T}{\partial \alpha} = \frac{-DQ"_{sun}}{I^2\partial R_{AC}/\partial T - 4\,\epsilon\sigma\pi DT^3 - \pi Dh} \qquad \frac{\partial T}{\partial T_\infty} = -\frac{\pi Dh + 4\epsilon\sigma\pi DT^3}{I^2\partial R_{AC}/\partial T-4\epsilon\sigma\pi DT^3-\pi Dh}$$

$$\frac{\partial T}{\partial I} = \frac{-2IR_{AC}}{I^2\partial R_{AC}/\partial T - 4\epsilon\sigma\pi DT^3 - \pi Dh} \qquad \frac{\partial T}{\partial Q"_{sun}} = \frac{-\alpha D}{I^2\partial R_{AC}/\partial T-4\epsilon\sigma\pi DT^3-\pi Dh}$$

where $h=\frac{k}{D}\,10^{A}[16]$, $A=a_0+a_1\log Re_D+a_2(\log Re_D)^2$, $a_0=-0.070431$, $a_1=0.31526$, $a_2=0.035527$

$$\frac{\partial R_{AC}}{\partial T} = \frac{k_s(R_1+R_2)[\alpha_1R_2R(20)_1+\alpha_2R_1R(20)_2]-R_1R_2[\alpha_2R(20)_2+\alpha_1R(20)_1]}{(R_1 + R_2)^2}$$

k, ν are assumed constant for small temperature changes

frequently can differ by several ft/sec along the conductor span, changes in conductor temperature are often in excess of 10°C simply as a result of uneven wind distribution along the route of the conductor.

The sensitivity parameters which appear in Table 9 are obviously functions of numerous factors and it is difficult to graph or display the trends in the sensitivity parameters without establishing a set of fixed parameters. A standard reference set of parameters was therefore selected to simplify the results and these values are given in Table 10. Also the correlation for the convective heat transfer coefficient with respect to wind direction and velocity was adopted from Reference [27].

Table 10. Input Variable Reference Set.

Variable	Value
absorptivity	0.5
emissivity	0.5
ambient temperature	25°C
sun radiation	1000 W/m^2
wind direction	90° (normal flow)
wind velocity	2 ft/sec (0.61 m/s)
conductor types	Curlew, 54/7, 1033 kcmil Linnet, 26/7, 336 kcmil
current (75°C ampacity)	958 amps (Curlew) 492 amps (Linnet)

The graph of the wind velocity sensitivity parameter, Figure 22, illustrates that the conductor temperature is far more sensitive to changes in wind velocity when wind conditions are nearly calm. At high wind velocities, a change in velocity has only a minor effect on the conductor temperature. Under normal conditions, it is far more common for the wind velocity to show large variations when conditions are calm. Therefore, calm weather conditions promote large variations in the local conductor temperatures as a result of variations in wind velocity from point to point along the route of the transmission line. As the wind velocity increases, the conductor temperature becomes less sensitive to changes in wind velocity and the temperature becomes more uniform.

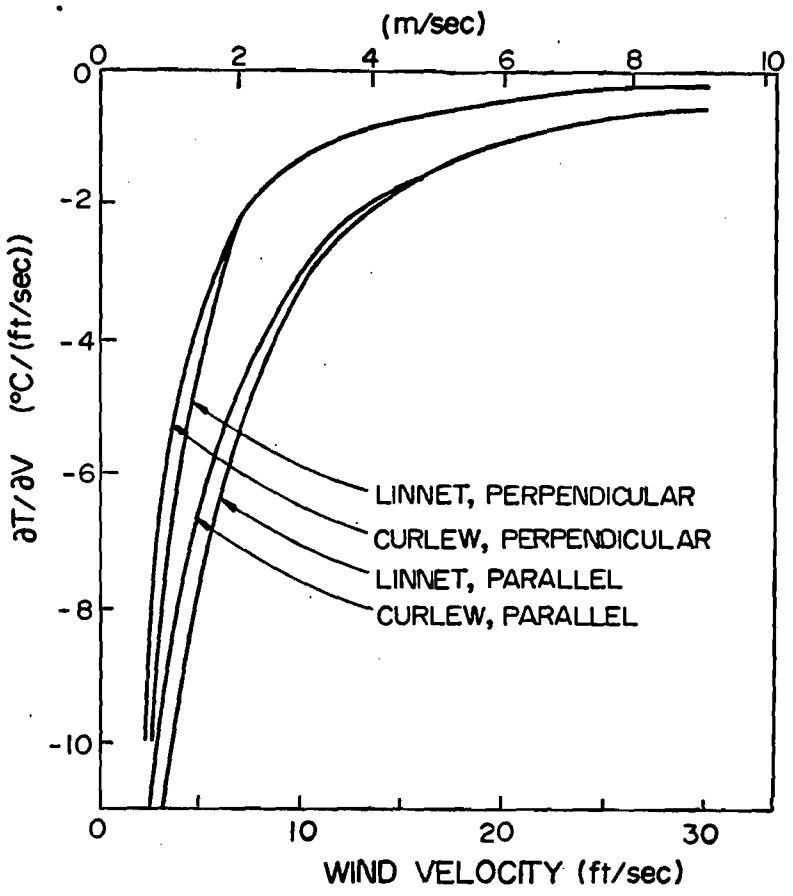

Figure 22. Wind Velocity Sensitivity Parameter

The graph of the wind direction sensitivity parameter shown in Figure 23 confirms that the conductor temperature is more sensitive to changes in wind direction as the wind blows down the axis of the conductor. This result implies that a wind oriented along the axis of the conductor will be accompanied by larger swings in the conductor temperature than when the wind blows across the conductor. Therefore, when the wind blows down the axis of the conductor, the location of a critical span will have a tendency to move from one location to another, while cross-flow wind will promote a more stable location for the critical span.

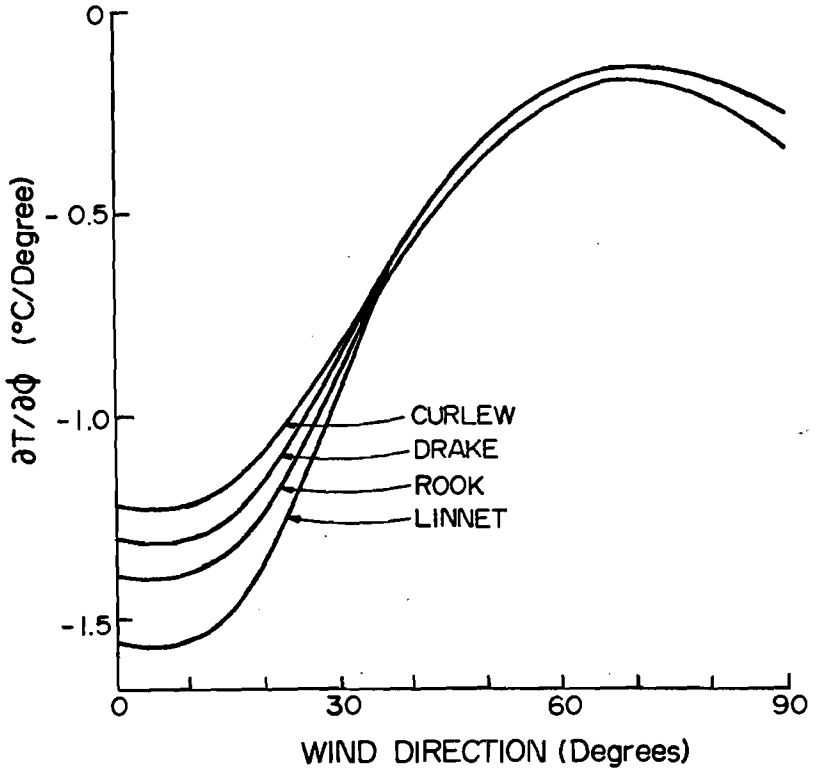

Figure 23. Wind Direction Sensitivity Parameter

The current sensitivity parameter is plotted in Figure 24. These curves show how the current affects the temperature for a wide range of conductor sizes. When a conductor at a given load has the current changed by a fixed amount, the larger conductor will experience a smaller change in temperature, while the temperature of the smaller conductor will change a greater amount. At higher currents the sensitivity to a change in current is greater for all conductor sizes. Therefore, a heavily loaded small conductor will experience large temperature changes for relatively small changes in current. Large, lightly loaded conductors are less sensitive to changes in current.

The implication of the sensitivity parameters shown in Figures 22, 23 and 24 can be applied to the task of predicting the location of a critical span. The desire to locate a critical span will coincide with conditions that lead to a maximum conductor temperature. A system operator would have the greatest need to know the location of a critical span when the current is greatest and the wind velocity is the lowest and in a direction down the axis of the conductor. This combination of events maximizes the heat generated in a conductor and minimizes the convective

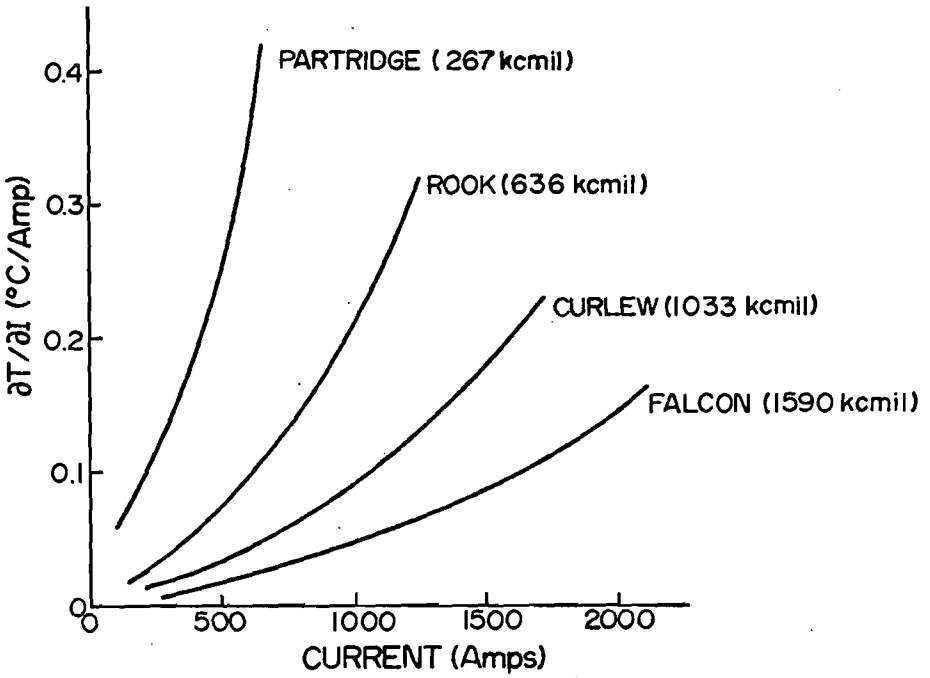

Figure 24. Current Sensitivity Parameter

cooling of the surface of the conductor. Unfortunately, the sensitivity parameters show that the same set of circumstances can cause a large variation in conductor temperature along the route of the line. Therefore, when there is the greatest need to locate a critical span, conditions are such that the task of predicting the location of a critical span becomes the least likely to succeed. Periods when the wind velocity is relatively high and sustained increase the convective cooling and reduce the chance of overheating an overhead conductor. During this type of weather, the location of a critical span is most likely to remain fixed and the probability of predicting that location becomes greater.

While the convective mode of heat transfer plays the dominate role in controlling the conductor temperature, it is by no means the sole factor influencing the selection of a critical span or spans. Radiation also influences the temperature, because the conductor emits radiant energy and it also absorbs incident solar energy. Therefore, any change in radiative conditions such as variation in cloud

cover along the route of the conductor will influence the selection of a critical span. Obviously, the extent and variation in cloud cover is, in a practical sense, unpredictable and the sun's influence on the conductor temperature makes the job of locating a critical span solely on the basis of radiative effects a very difficult one.

The effect of radiative properties of the conductor surface on the temperature are shown by the sensitivity parameters $\partial T/\partial \alpha$ and $\partial T/\partial \epsilon$ in Figures 25 and 26. The emissivity sensitivity parameter is negative because an increase in ϵ decreases the conductor temperature. The sensitivity to ϵ increases as the incident solar energy increases, causing the conductor temperature to increase and enhancing the importance of radiation emitted from the conductor. The absorptivity sensitivity parameter shown in Figure 26 is always positive, because an increase in α always produces an increase in conductor temperature. Under the extreme conditions of 1000 W/m^2 of incident solar energy, the conductor temperature will increase by about 10^oC if the conductor changes from a perfect reflector to a perfect absorber of solar energy (change of α from 0 to 1). These two sensitivity parameters give an indication of the changes in conductor temperature that could be achieved by coating the outer surface of the line with a low absorptivity, high emissivity material.

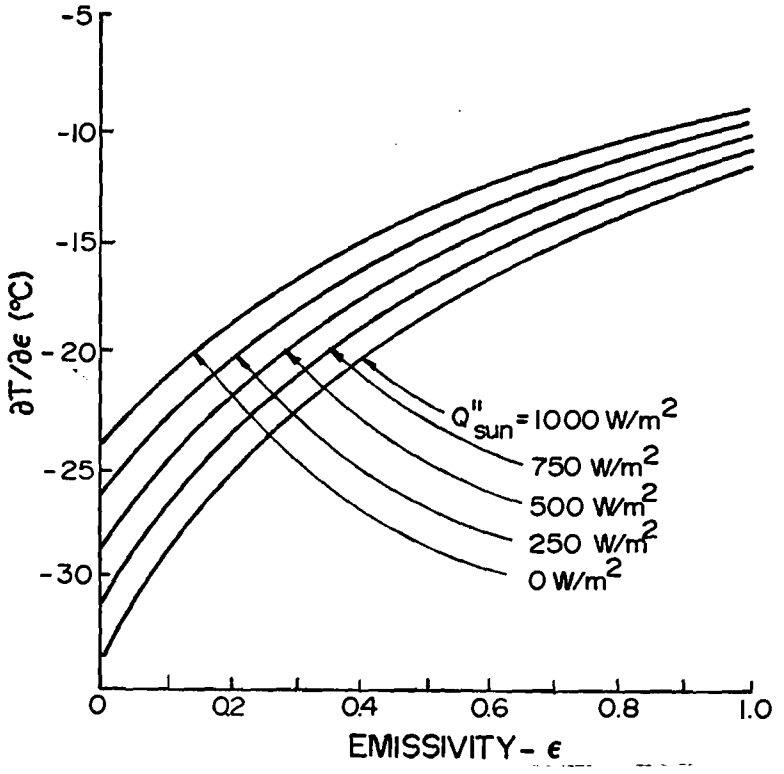

Figure 25. Emissivity Sensitivity Parameter

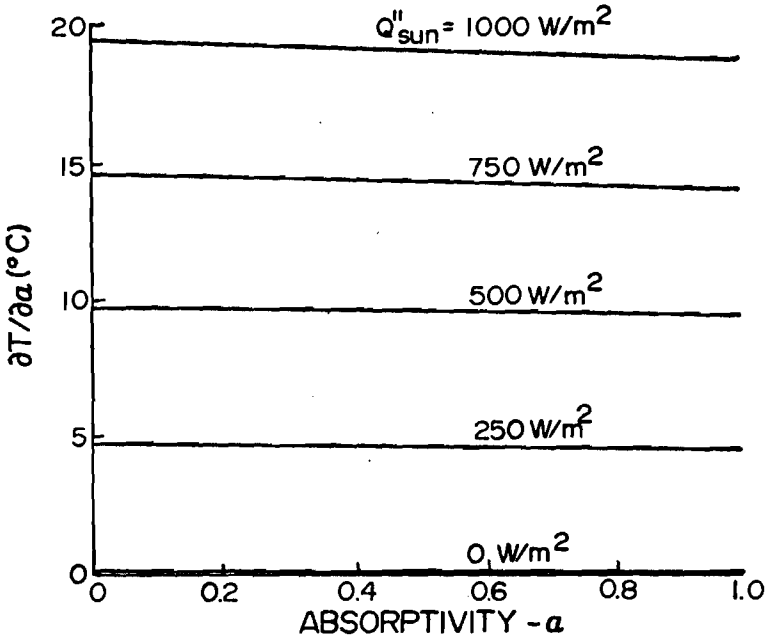

Figure 26. Absorptivity Sensitivity Parameter

The sensitivity parameter is a mathematical concept that has been used to help predict those weather and line operating conditions that will aid in locating a critical span. To verify the predictions of the sensitivity parameter analysis, an experimental program was devised.

REMOTE WEATHER STATION SITES

The remote site program consisted of the test span located at Forest Park (See Section 5) and four other weather stations placed at various distances from the Forest Park test site as shown in the map in Figure 27. The Forest Park test span will be referred to as the Base Station and the other weather stations will be called Remote Sites.

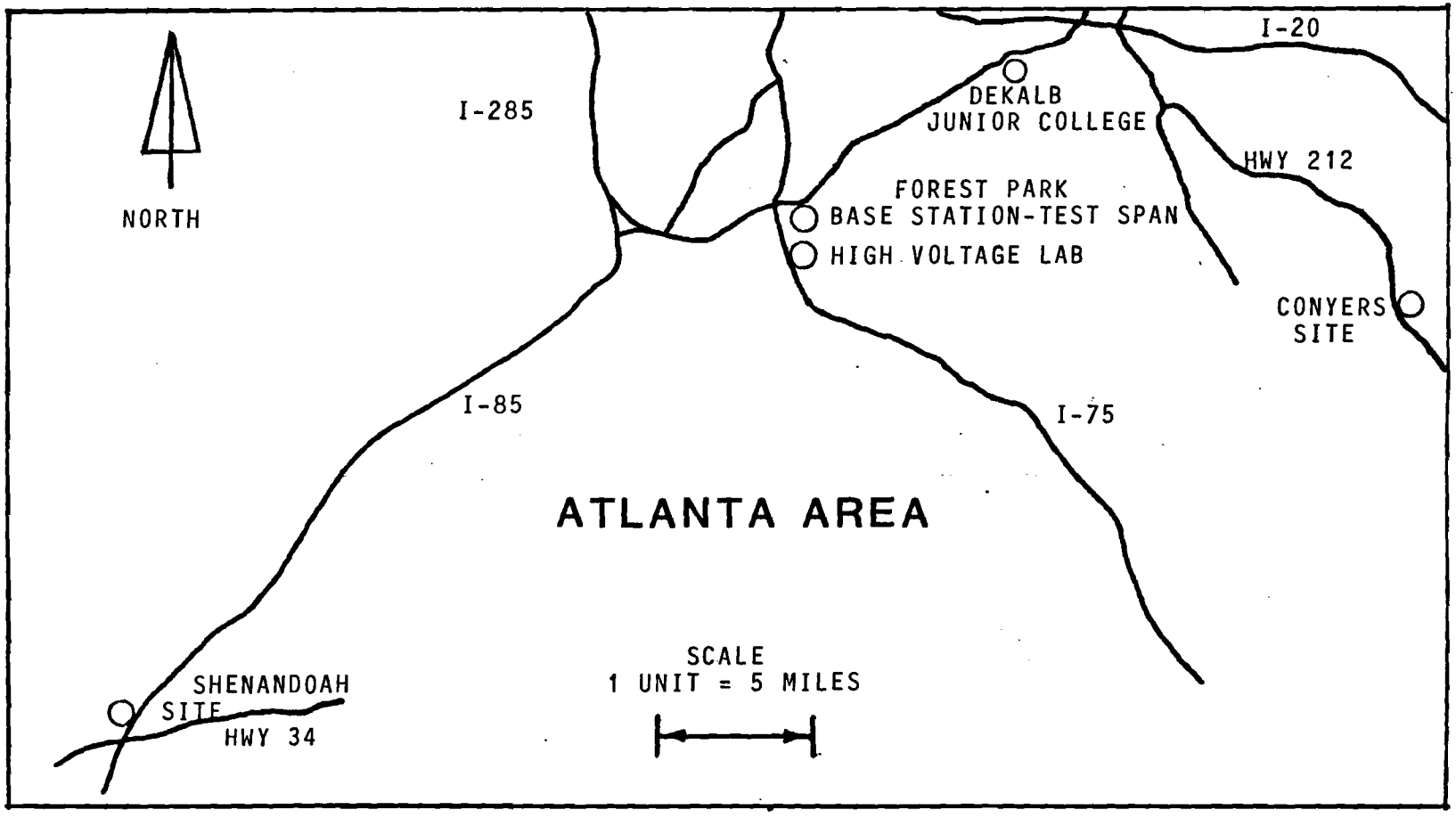

Figure 27. Location of Test Span and Remote Sites

Weather data was collected at the Base Station and at the four Remote Sites during the same time intervals. At the same time, the test span was operated and the temperature of the conductor was measured with the array of thermocouples located along the test span. DYNAMP was then run with the five sets of weather data - one set collected at the Base Station and four sets from the Remote Sites. The output from DYNAMP therefore could be used to predict the temperature of a hypothetical line located at each of the four remote sites as well as the temperature of the real line located at the base station. These data then could be used to show the temperature variations that a conductor would have at different locations as a result of different weather conditions. Also these data could be used to show how the conductor temperature would vary from spot to spot at the same time and ultimately support the predictions provided by the sensitivity parameters.

Three of the four remote sites were chosen because the required weather data was already available and recorded by existing equipment in five or fifteen-minute time intervals. Equipment to measure and record weather data at a fourth remote site was assembled and installed when no other existing location could be found which could provide weather data in less than hourly intervals. Table 11 contains a brief summary of information for the four Remote Sites plus the Base Station.

Table 11. Weather Station Site Summary

Site	Distance From Test Span (miles)	Time Interval For Data (min)	Data Interpretation And Entry	Number of Data Points
Base	0	5	automated	26,400
Remote 1	1.0	5	automated	6,500
Remote 2	7.6	15	manual	1,400
Remote 3	18.3	5	manual	4,300
Remote 4	25.6	5	automated	4,100

Remote site number one was located one mile (1.6 km) south of the test span. A pole was set at this site and the weather station sensors were installed on the top of the pole. A desktop microcomputer and data acquisition system were used to read the sensors once each minute. These readings were averaged for five-minute periods and stored on diskettes.

Remote sites number two and three are located 7.6 miles (12.2 km) northwest and 18.3 miles (29.3 km) east of the test span, respectively. The weather stations at both sites are owned by the Department of Natural Resources of the State of Georgia and used strip chart recorders to store data. Data on these charts was averaged visually and typed into a portable microcomputer for storage on diskette. The data from remote site three was averaged in five-minute intervals. The chart scale on remote site two made it necessary to average data in fifteen-minute intervals. The ambient temperature from the base weather station was used for remote site number three, because it did not have a sensor to read ambient temperature.

The Shenandoah Solar Center, 25.6 miles (40.1 km) southwest of the test span, served as remote site number four. This facility gathers and records weather data continuously as part of various research projects. Weather data was sampled every twelve seconds and stored as one-minute averages. For this investigation, the one-minute averages were transferred to a desktop computer using a modem. The computer then averaged the data in five-minute intervals and stored the results on diskette.

Recognizing the high probability of multiple critical spans, it is natural to ask how closely spaced line monitors or weather stations must be in order to accurately predict the conductor temperature for a line of reasonable length. To answer this question, weather data was collected at the test span and the four remote stations. The weather data were then run through DYNAMP and the line temperatures were calculated for conditions at the five sites. Since the computer program can accurately predict the conductor temperature of a span located at each of the sites, the data can be used to show the types of temperature variations that will occur along the route of a transmission line.

The data shown in Figure 28 and 29 are representative of the remote site weather data and the temperature predictions of DYNAMP. Figure 28 shows the weather conditions measured at the test span (Base Station) and the corresponding computer predicted conductor temperatures. Figure 29 shows temperatures for the same time but for data collected at Remote Site 1. For this particular day the wind velocity was fairly strong, averaging about 9 ft/sec (2.7 m/s). As a result, the difference in predicted temperature of the two spans located 1 mile (1.6 km) apart was reasonably small and rarely exceeded 15°C. However, on days when the wind was quite calm, variations in conductor temperature from one weather site to another ranged as high as 50°C. This type of variation was predicted by the sensitivity parameter $\partial T/\partial V$.

To illustrate how the conductor temperature can change from one location to another, the difference between the temperatures measured at the test span and those predicted at all of the weather sites is plotted for the Base Station and each of the remote weather stations in Figure 30. These data show errors that could result when a line monitor at one location is used to predict the temperature at another location. For example, 50 percent of the weather data collected at the test span and run through the program produced temperatures that were within 2°C of the actual line temperature. If the weather station was moved away 1 mile (Remote Site 1), then 50 percent of the time the program would be within 6°C of the conductor temperature at the test span. Moving the weather station further from the test span would produce further reductions in accuracy. The remote site weather data can also be used to verify the predictions of the sensitivity parameter study.

In Figure 31 the difference between the computer predicted temperature and the measured conductor temperature is shown for the four remote weather stations and the base station. Weather data was collected at the five sites for the same period of time. All five sets of data were put into DYNAMP and the predicted temperatures were compared with the measured temperatures for different wind velocities. When the weather data was collected at the location of the test span, the accuracy was quite good and it averaged less than 6°C. As the weather data was collected further from the test span, the accuracy was reduced, because the weather at the remote sites rarely coincided with that at the test site. Also the accuracy decreased as the wind velocity decreased because the line temperature

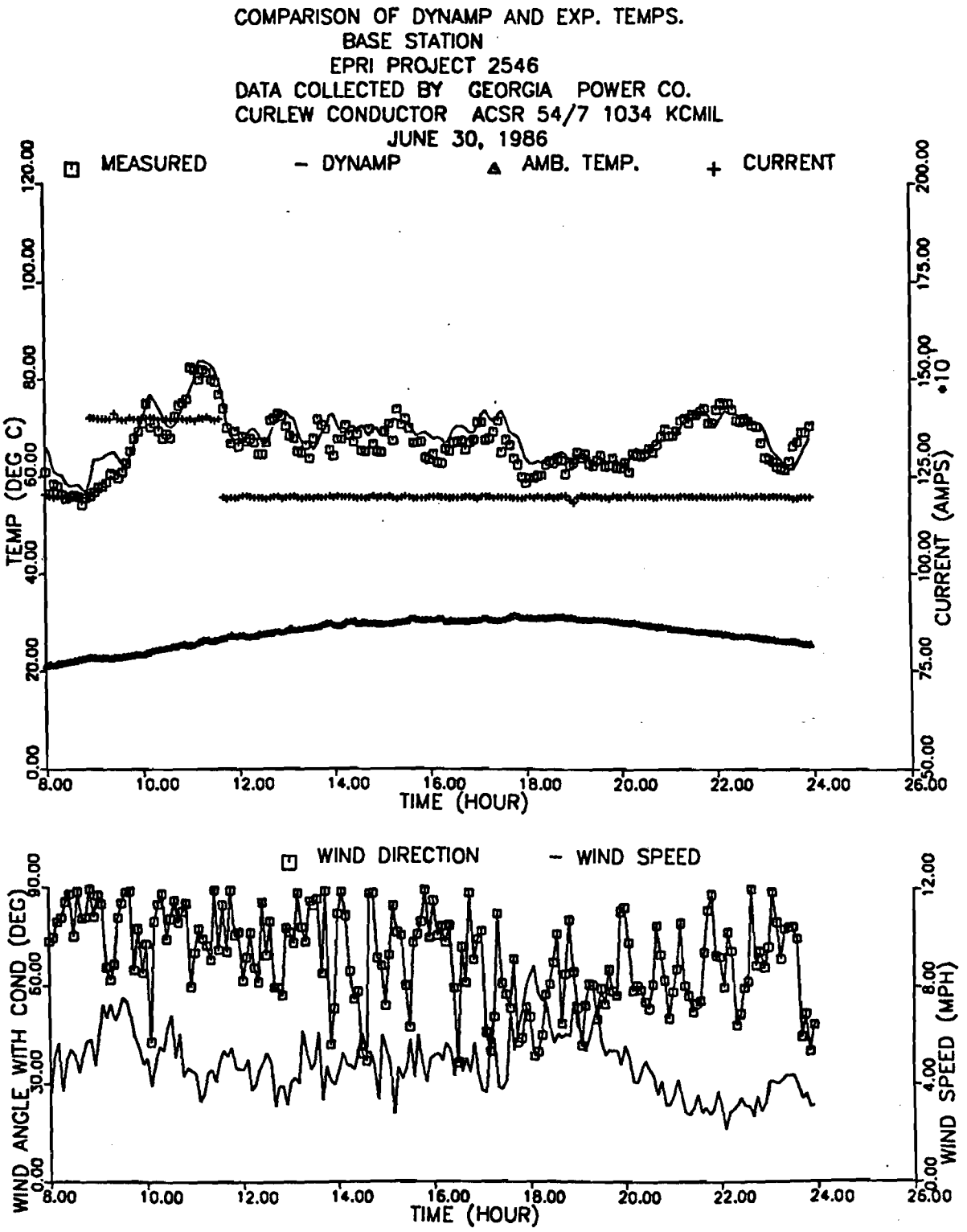

Figure 28. Measured and predicted Temperatures for Base Station

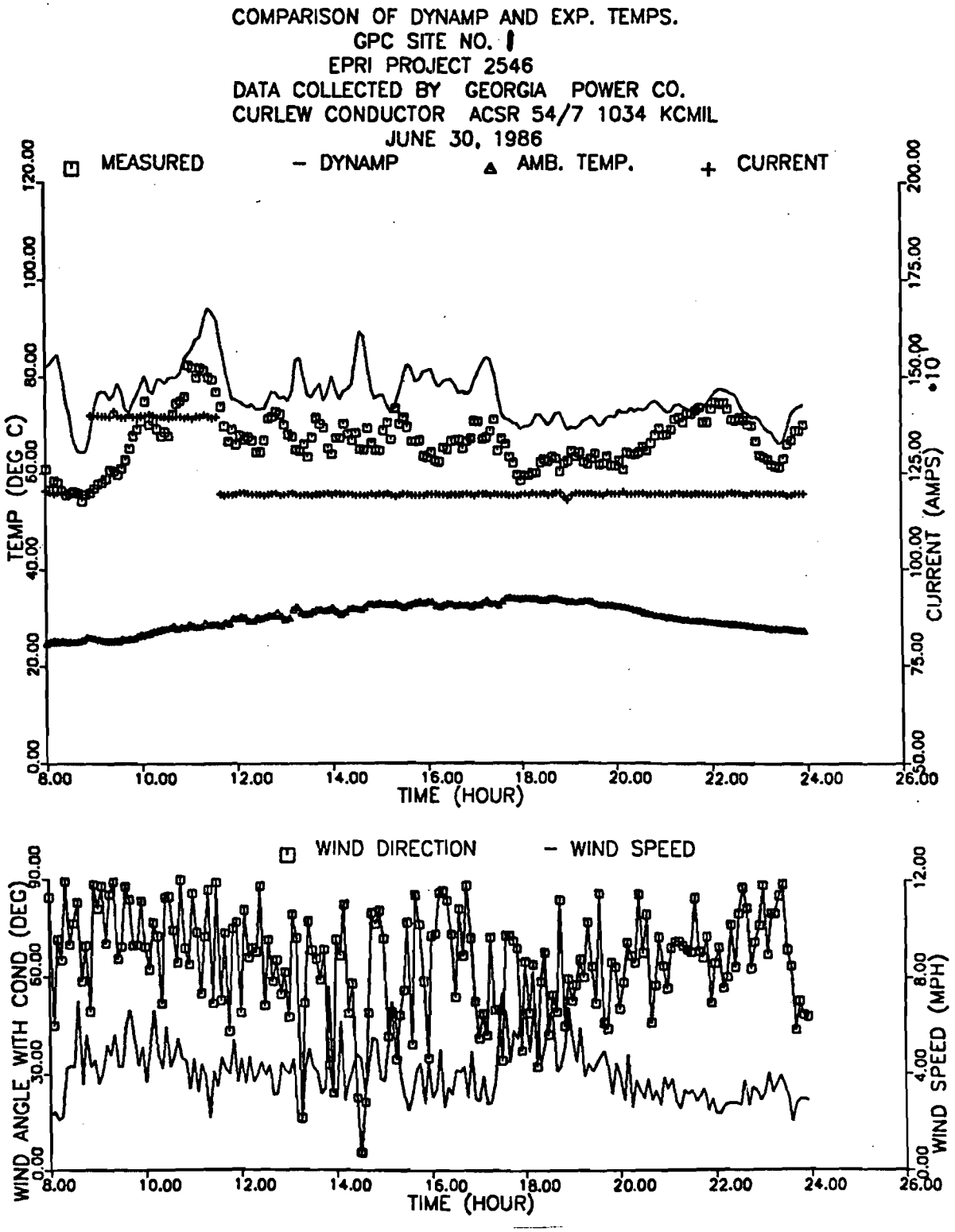

Figure 29. Measured Temperature at the Base Station and Predicted Temperature at Remote Site 1

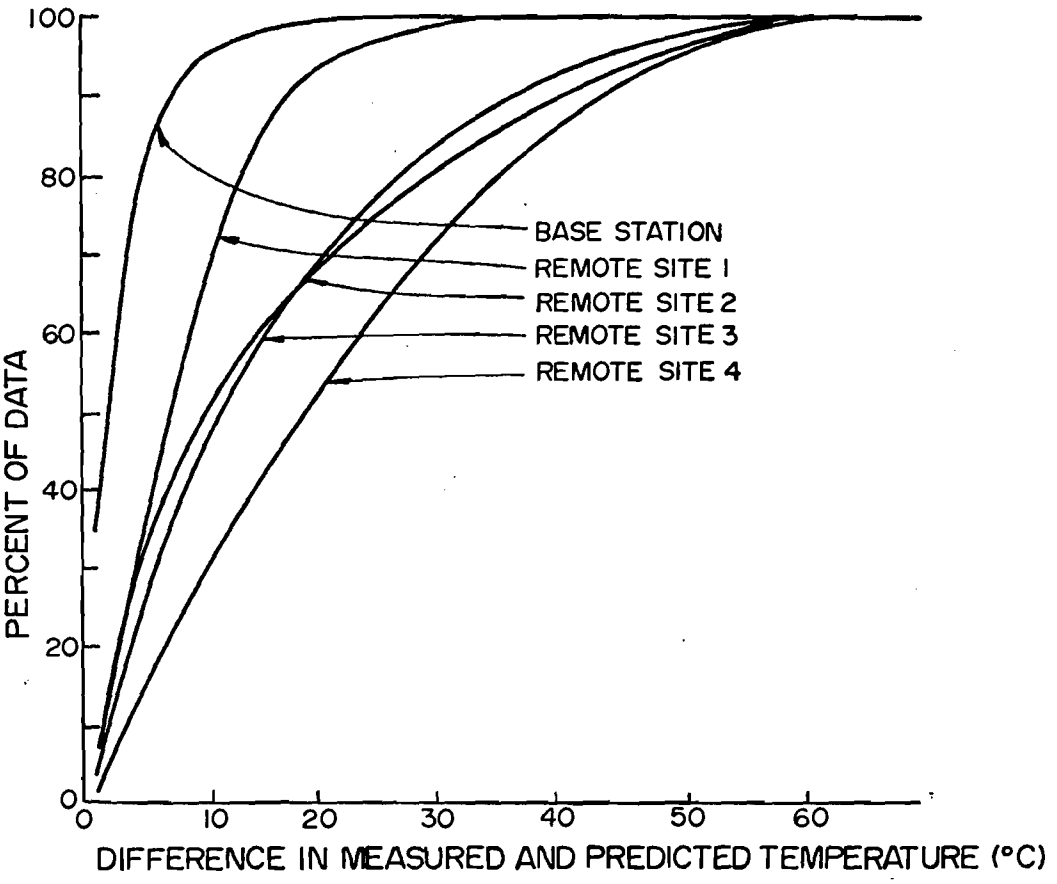

Figure 30. Errors in Predicted Conductor Temperature as a Function of Distance Between Span and Weather Station

became more sensitive to changes in the wind and the small variations in wind velocity from location to location produced large changes in the conductor temperature. The data in Figure 31 shows that if a single monitor is expected to predict the temperature of another span about 1 mile away (remote site 1) during conditions of no wind, average errors of about 15°C can be expected. If it is expected to predict the temperature of a span between 7 and 25 miles away, average errors in excess of 30°C can be expected.

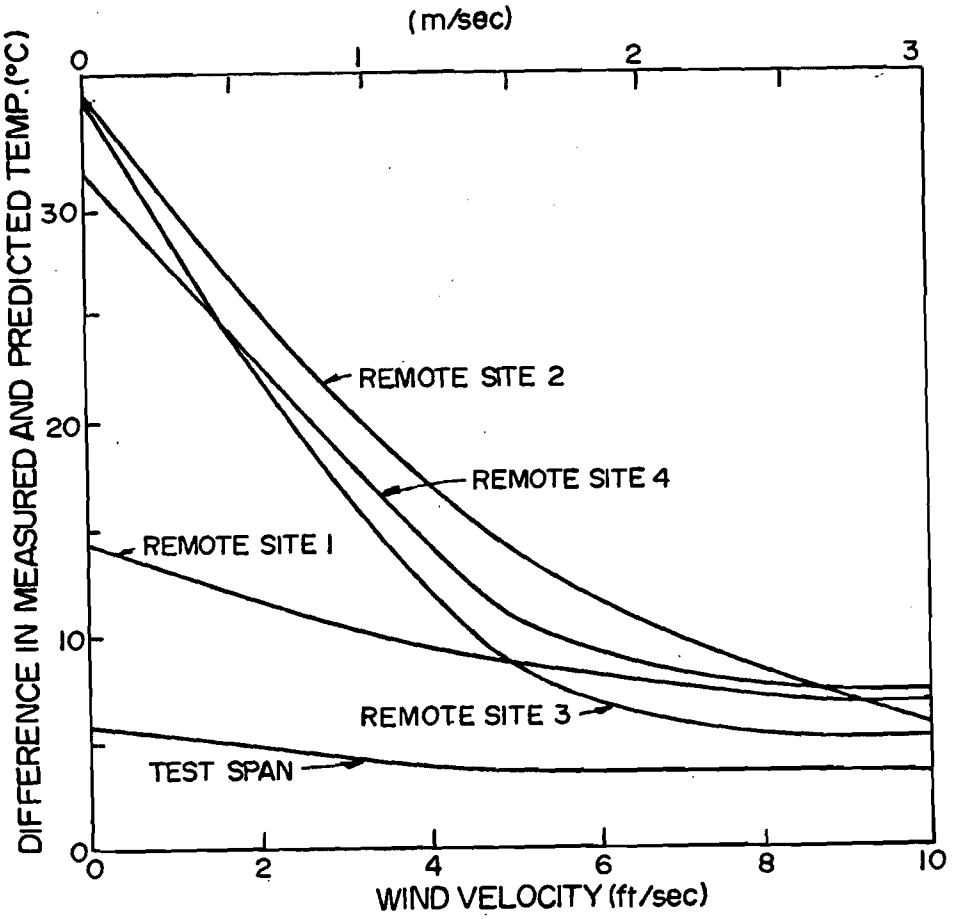

Figure 31. Errors in Predicted Conductor Temperature as a Function of Wind Velocity for Five Weather Stations

The curves in Figure 32 are similar to those which appear in Figure 31 except that the temperature differences are plotted as a function of wind angle instead of wind velocity. These curves show the general decrease in program or monitor accuracy as the wind blows down the axis of the conductor. As expected, the variation in conductor temperature increases as the distance to the weather station increases.

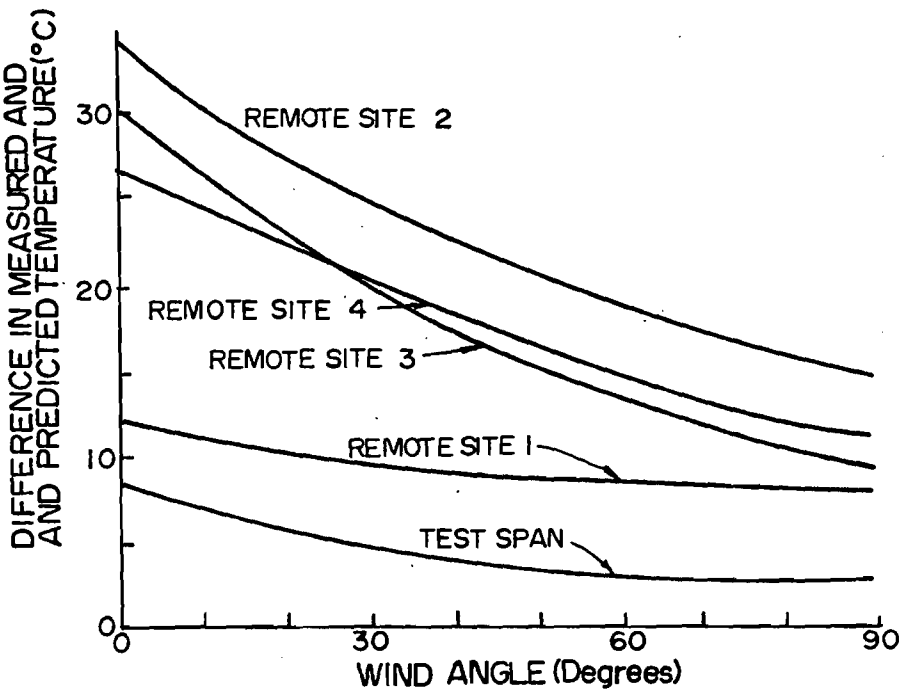

Figure 32. Errors in Predicted Conductor Temperature as a Function of Wind Direction for Five Weather Stations

The sensitivity analysis, the weather data collected at the five weather sites and the computer predicted temperatures for the five locations all confirm the following conclusions:

1. It is unlikely that a single critical span exists in a transmission line. Multiple critical spans are more likely and the location and number of critical spans move from one spot to another as a function of changing weather conditions.
2. The location and number of critical spans is predominantly dictated by weather factors, line orientation and terrain.
3. On calm days the number of critical spans increases and their movement from span to span becomes more frequent.
4. Wind that blows down the axis of a conductor causes an increase in the number of critical spans and promotes movement of the critical span from one location to another.

5. Thermal line monitors and weather stations coupled with computer programs will be least successful in predicting the critical temperature of a transmission line when the average wind velocity is low, when the wind blows down the axis of the conductor and when the current levels in the circuit are high.
6. Line current and weather conditions which produce the greatest thermal demand on the system (resulting in the highest average conductor temperature) are identical to those that make the location of the critical spans most difficult to predict.
7. On very calm days line monitors and weather stations must be closely spaced, probably no more than 1-2 miles apart for the type of terrain in this study, to assure accurate conductor temperatures. When selecting monitor locations, each utility should consider its own terrain and evaluate how the spacing will affect the accuracy of a real-time line monitoring system. On days in which the wind velocity is high and sustained, an accurate conductor temperature can be obtained from much more widely spaced monitoring equipment.

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SECTION 9
EVALUATION OF LINE MONITORS

A survey was undertaken to determine what line monitors were commercially available. A total of four types of monitors were obtained. Of these, only one was found to be sufficiently reliable or accurate to evaluate. This monitor measures line temperatures and after this measured temperature is corrected for the influence of local wind conditions and heat sink effects, it sends a radio signal to a ground station. The monitor was installed on the test span in Forest Park on three seperate occasions. Results obtained during the first series of tests showed that the device on average was reading temperatures that were 10% low. The monitor was sent to the manufacturer for recalibration and repair. The jaws were adjusted so that the contact between the temperature sensor button and the conductor was improved. The power supply was adjusted so that the threshold current was reduced from 500 amperes to 150 amperes. Also the radio signal output from the device was reduced from 2 watts to 250 mw. The monitor was then calibrated in a wind tunnel and returned.

The monitor was re-installed on the test span for approximately one week. A plot of randomly selected temperatures measured during these tests are shown in Figure 33. These data indicate that the monitor indicates a temperature that is usually within 5 ^{o}C of the measured line temperature.

After the monitor was re-calibrated by the manufacturer, it was forwarded to KG&E for use in field tests described in Section 5. After the KG&E field tests were completed, the monitor was returned to Georgia Power and reinstalled on the test span for a period of ten days. The calibration was rechecked to verify that no significant drift of the output of the device occurred during the KG&E test program. Examination of the data shows that no significant drift occurred, although individual temperature variations of 10 to 15°C were encountered (Figure 34).

During the ten day period that the monitor was in operation, weather data was also being collected. This procedure allows a direct comparison of the monitor results, the DYNAMP predictions and the temperatures measured by the line thermocouples. In general, both the monitor and the DYNAMP program gave good correlations,although periods did exist where the monitor temperatures differed from the measured conductor temperatures by 20°C. These comparisons are shown in Figures 35-40.

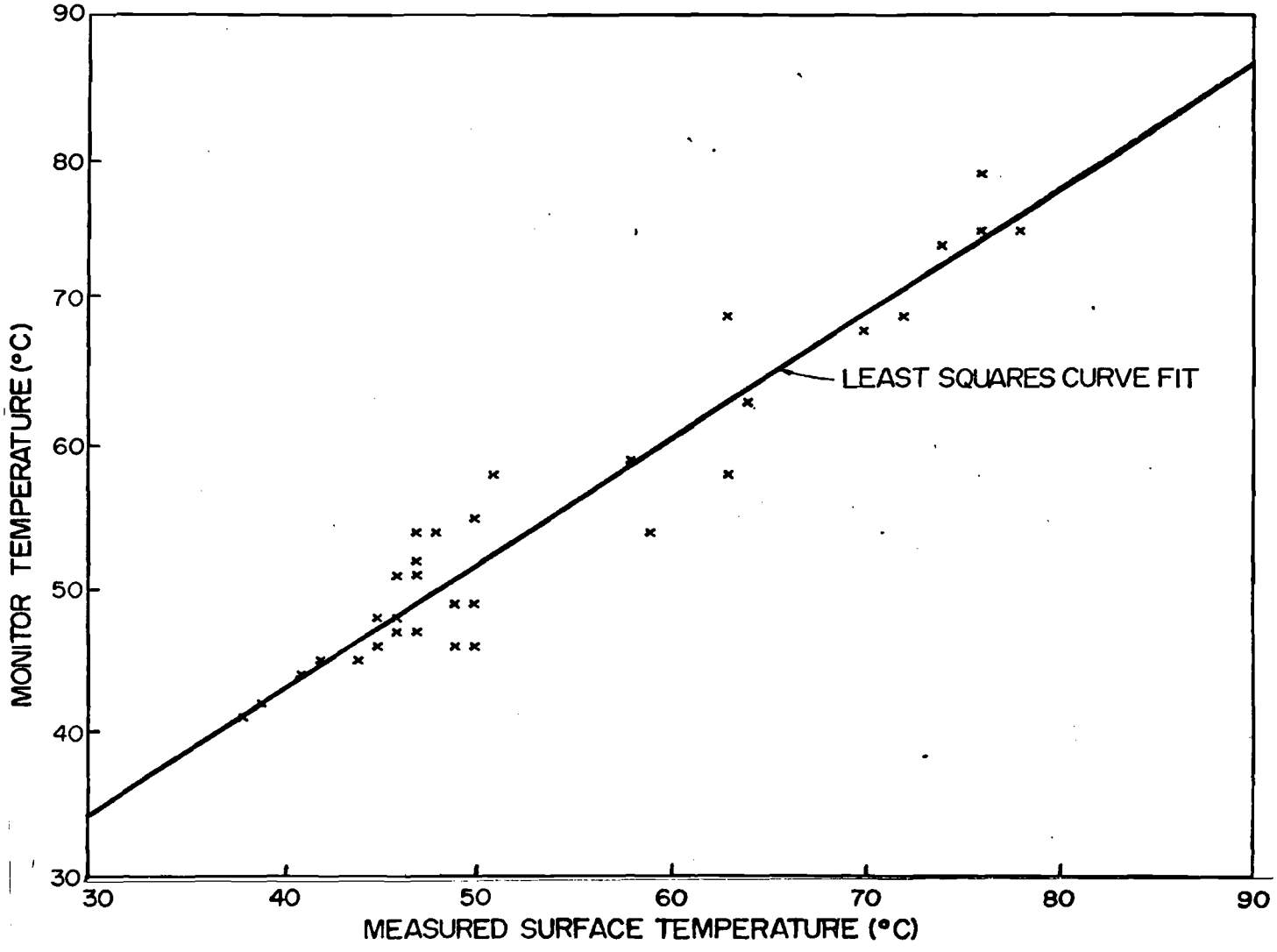

Figure 33. Initial Monitor Calibration Check

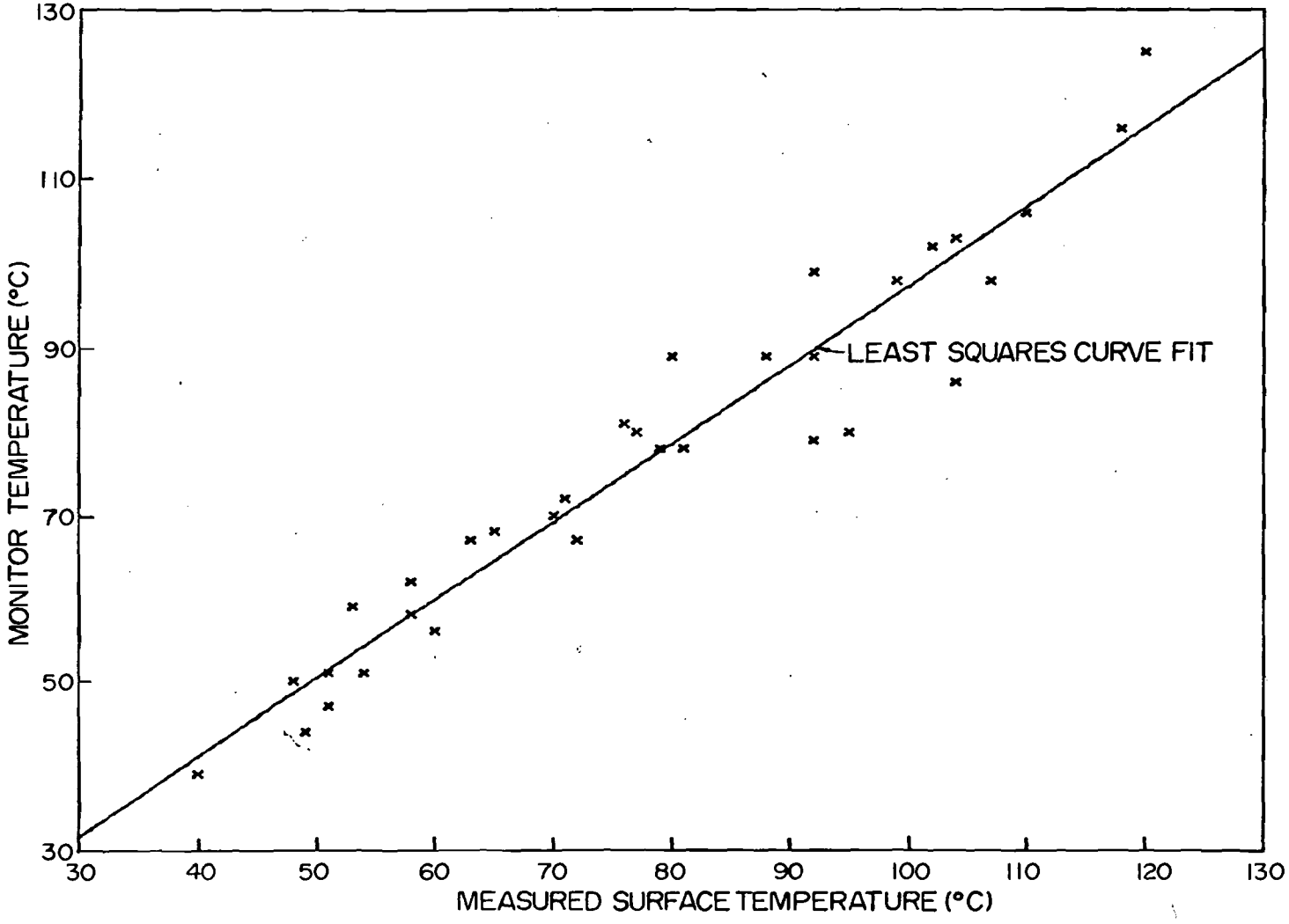

Figure 34, Final Monitor Calibration Check

Similar data was collected on October 17 and is shown in Figures 37 and 38. For this particular time period, DYNAMP gave good correlations while the monitor read approximately 20°C low at 8:00. At this time the wind was blowing parallel to the conductor. This figure implies that the errors experienced from the monitor are a function of the wind direction.

On October 23 at 19:00, the DYNAMP program predicted temperatures 20°C higher that those measured, as shown in Figure 39. This error corresponds to a time period where the wind velocity was under the wind velocity sensor threshold of 0.5ft/sec. The wind speed input to DYNAMP was 0 ft/sec while the actual wind speed was not recorded but was somewhere between 0 and 0.5 ft/sec. The lack of accurate wind velocity data resulted in a predicted temperature that was higher than that measured. During this same time period, the monitor temperatures remained within a few degrees of the measured conductor temperatures as shown in Figure 40.

The monitor and measured line temperatures were compared when the wind was oriented both parallel and perpendicular to the conductor and the results indicated that the monitor accuracy was affected by wind direction. The monitor tends to read high when the wind is blowing from the west on the monitor installed on a North/South line. This trend occurs because the back of the monitor shields the conductor from the wind and a local hot spot in the conductor is produced. Depending on the direction of the wind, the monitor can act as a heat sink, wind shield or combination of both, resulting in measured conductor temperatures that can be either higher or lower than the true temperature.

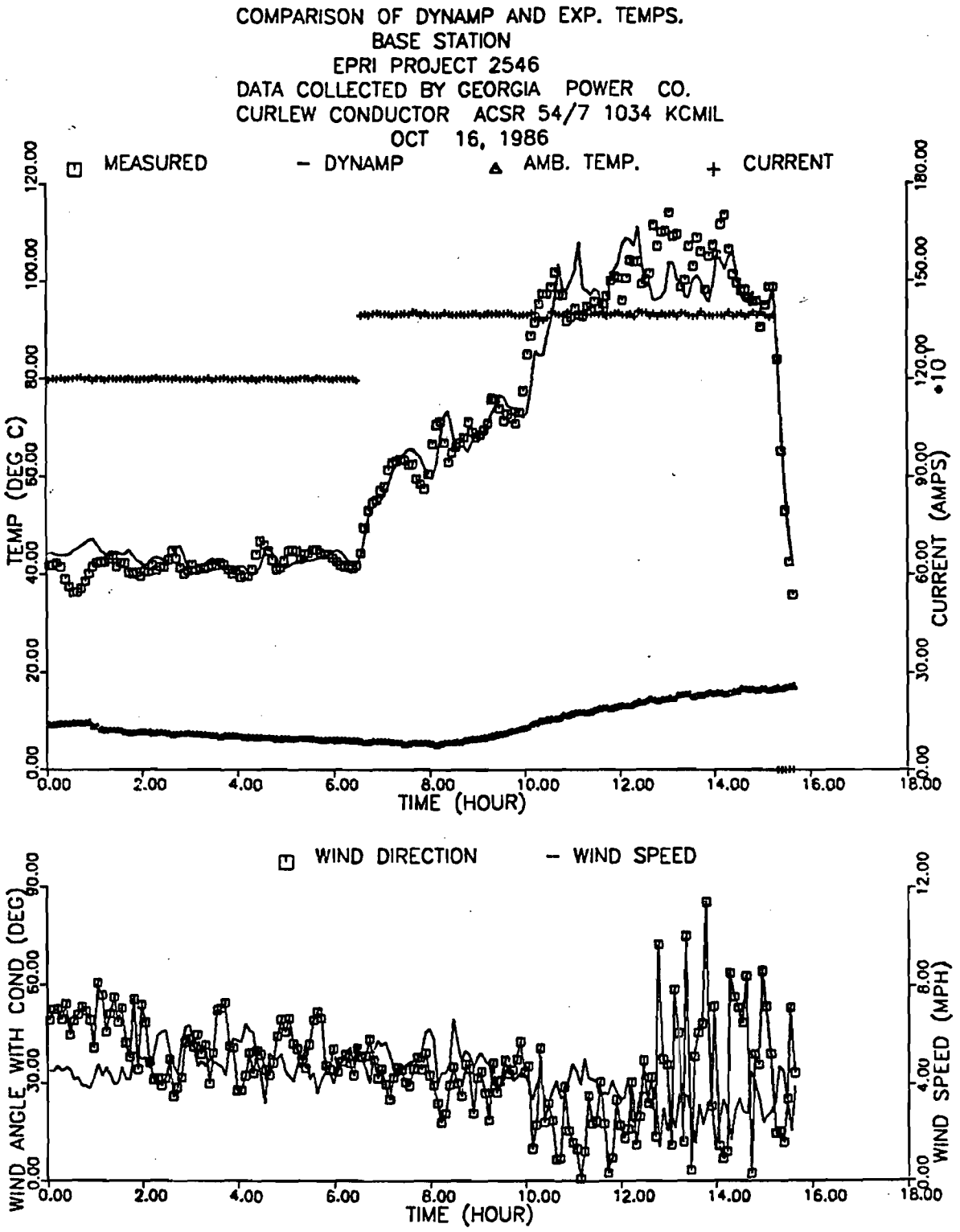

Figure 35. DYNAMP Predictions for Curlew Conductor on October 16, 1986

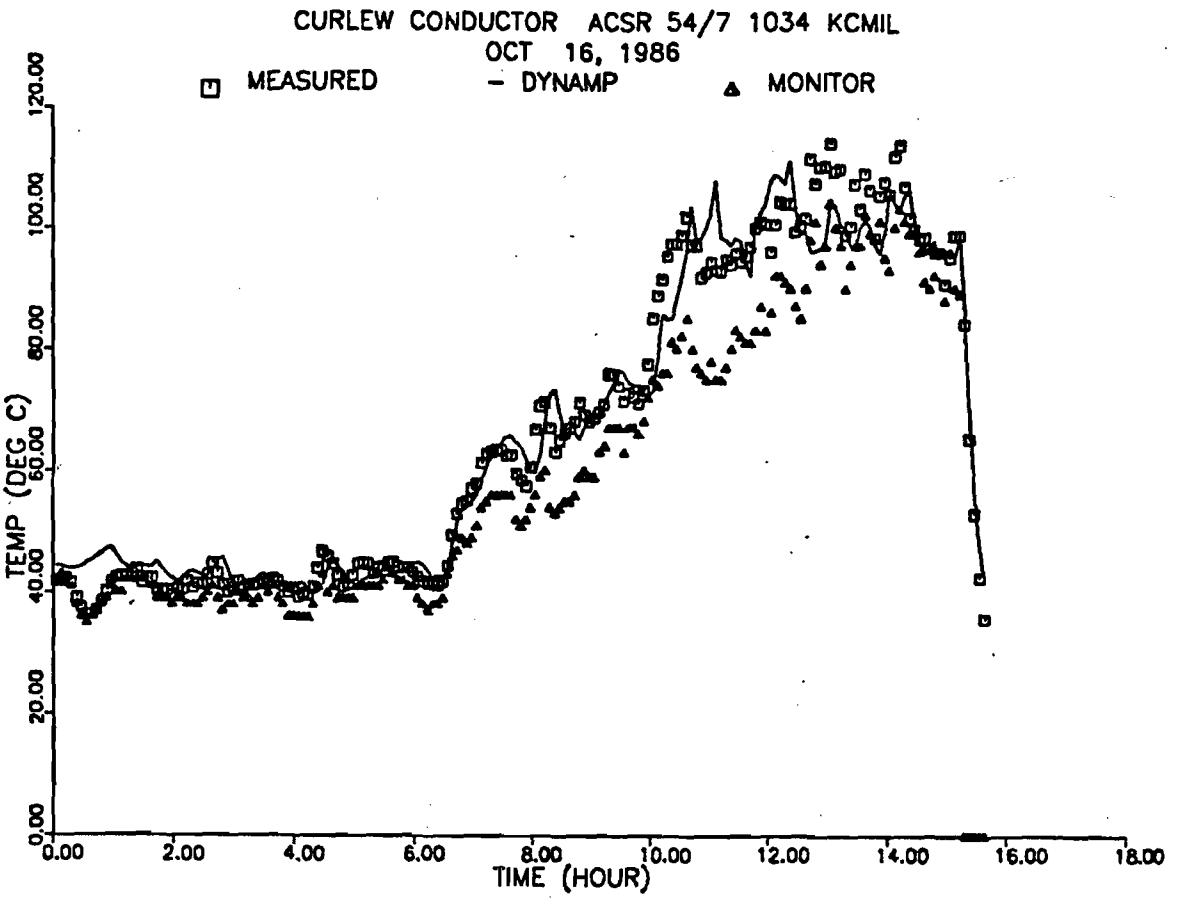

Figure 36. Comparison of Monitor and DYNAMP Predictions for Curlew Conductor on October 16, 1986

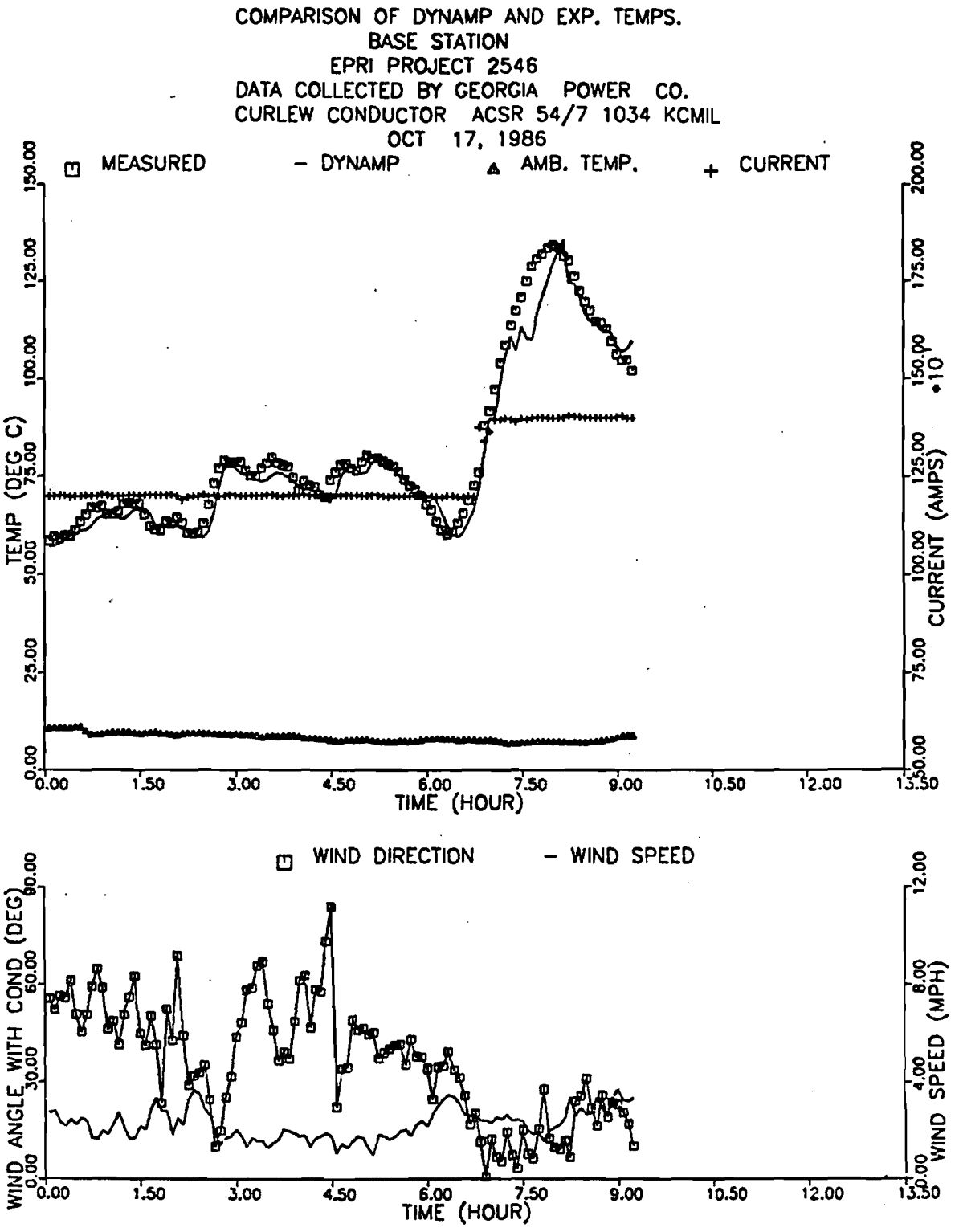

Figure 37. DYNAMP Predictions for Curlew Conductor on October 17, 1986

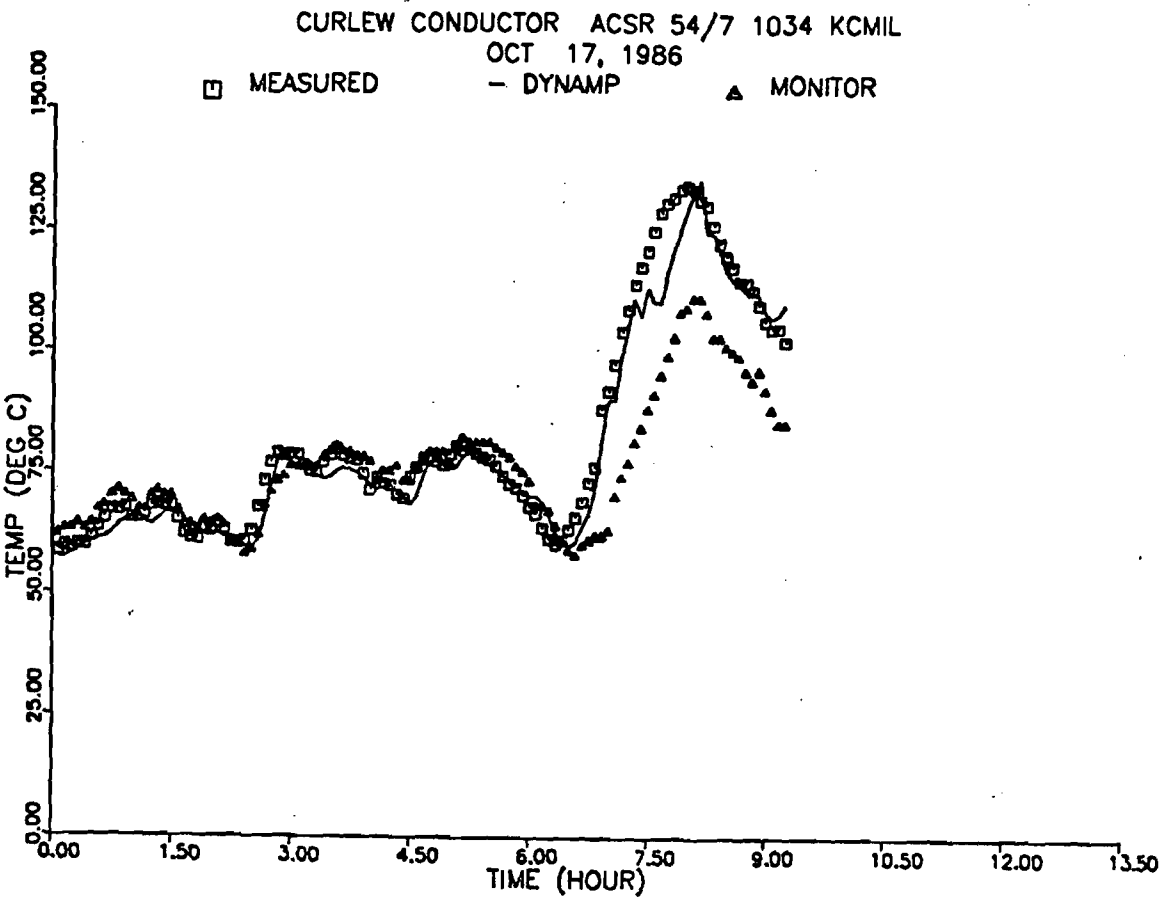

Figure 38. Comparison of Monitor and DYNAMP Predictions for Curlew Conductor on October 17, 1986

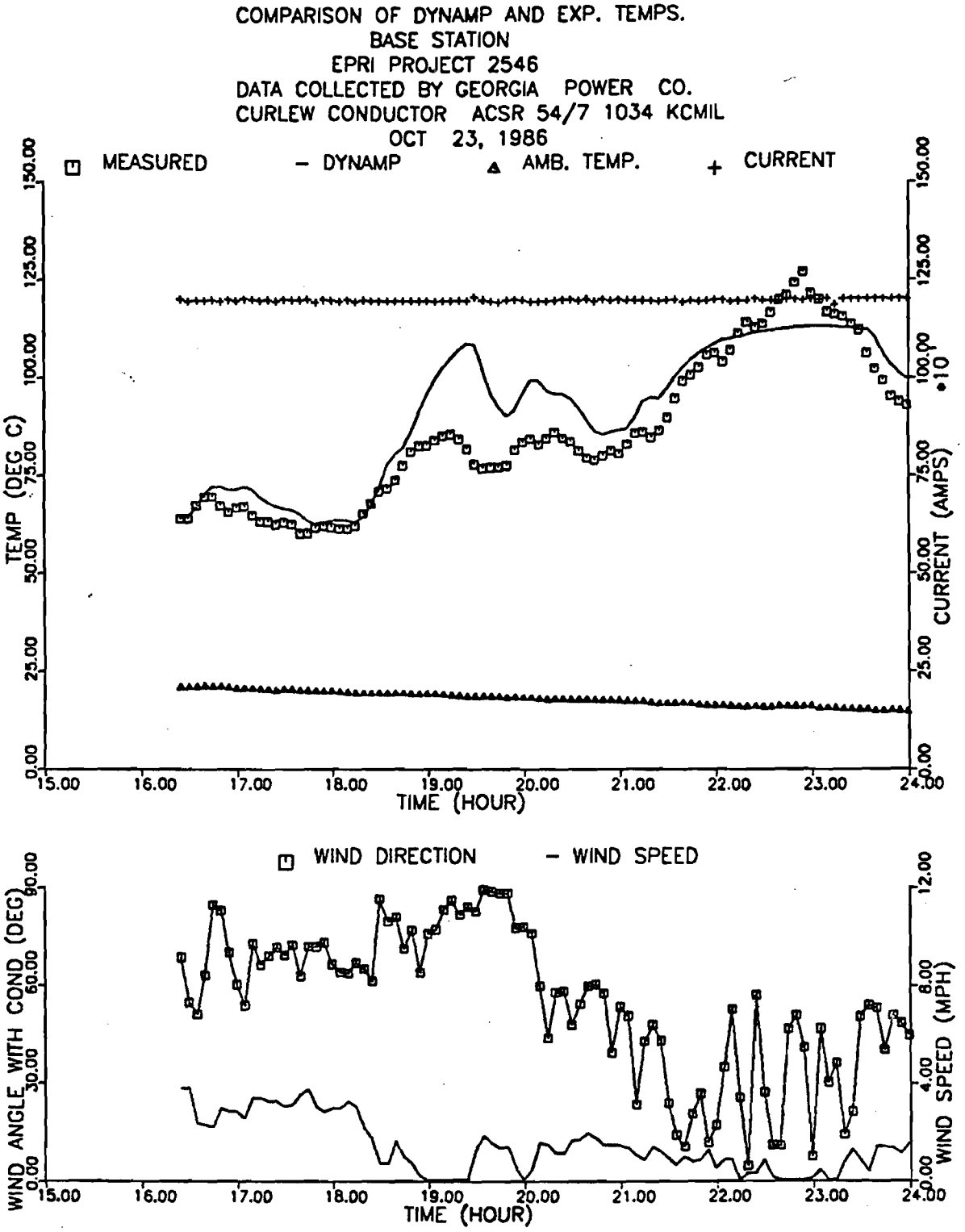

Figure 39. DYNAMP Predictions for Curlew Conductor on October 23, 1986

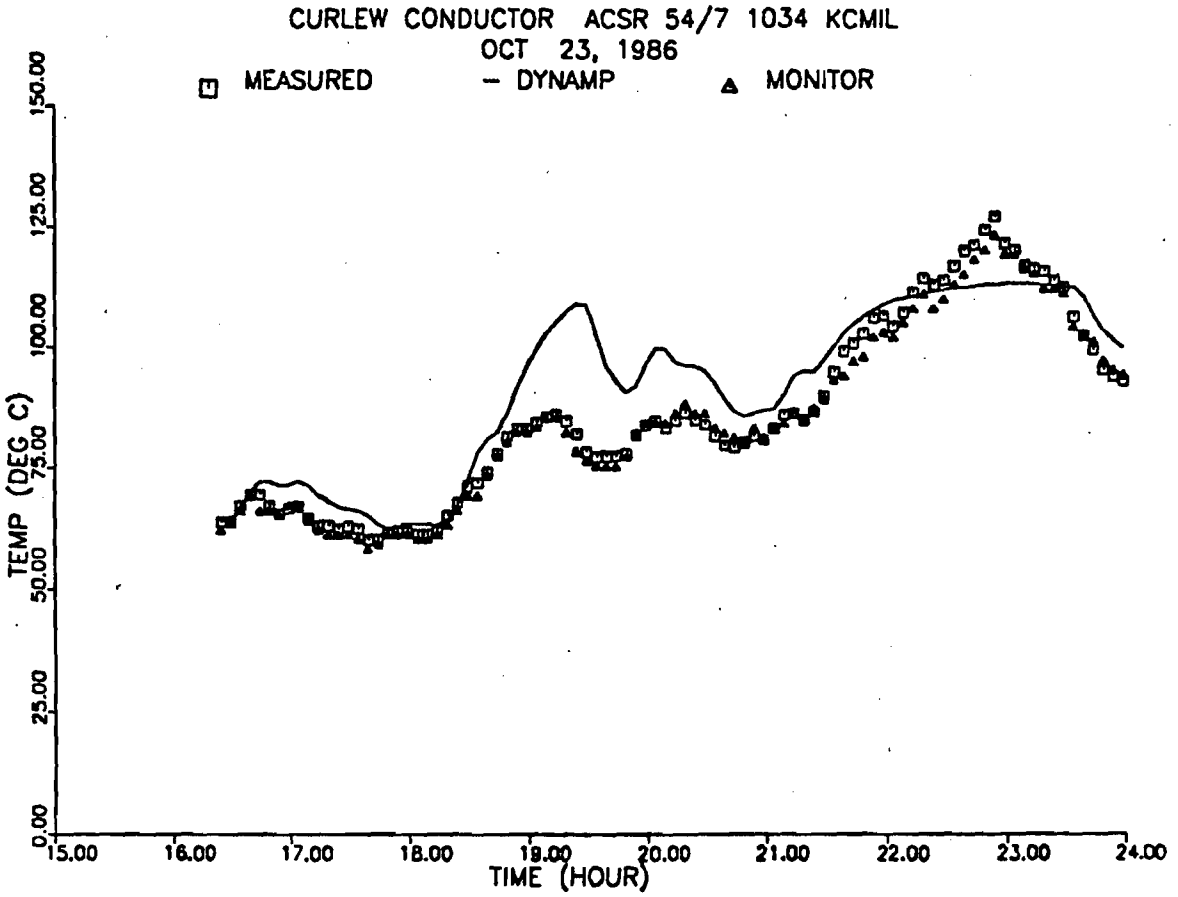

Figure 40. Comparison of Monitor and DYNAMP Predictions for Curlew Conductor on October 23, 1986

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SECTION 10

CONCLUSIONS

A real-time ampacity program called DYNAMP has been developed to predict the transient temperatures of overhead conductors. The menu driven program is simple to operate and it predicts real-time conductor temperatures that have been verified in two separate outdoor test programs and a series of indoor wind tunnel tests. When the program results are compared with temperatures measured with thermocouples attached to the test line, the program yields conservative results that are within ± 8°C over 90 percent of the time. The program requires input weather conditions of air temperature, wind speed and wind direction, all of which can be accurately measured with an inexpensive weather station located near the line. Therefore the real-time program can accurately predict conductor temperatures using only an inexpensive device to provide weather conditions for input information. The program does not require that any device be mounted directly on the conductor. The results of the program have shown that there are significant periods of time that the conductor temperature is lower than calculated by steady-state thermal models. However, it has also shown that there are brief periods when the conservative steady-state model will under-predict the conductor temperature, because wind speeds can fall below the values assumed for static rating schemes.

An analytical thermal model was used to predict radial temperature gradients in overhead conductors. This analysis showed that temperature differences in overhead conductors rarely exceed a few degrees Celsius, but under extremely high currents and high wind velocities, the temperature differences may approach 10°C. In general, however, temperature gradients in conductors are not large enough to adversely affect the accuracy of ampacity models which are based upon an isothermal conductor.

Several line monitors were selected for evaluation and one was attached to the Georgia Power test span and the Kansas Gas and Electric operating lines. The difference between the temperatures measured by the monitor and the

values recorded by the thermocouples attached to the test span was shown to be a function of line current, wind velocity and wind direction. Line monitors should be calibrated for different wind speeds and directions before they are attached to the line. If the monitor is properly calibrated it will have the same relative errors as the ampacity model based on the computer program. Line monitors are relatively new devices and they have not been extensively used by power companies in the past. As designs are improved and more experience is gained in using monitors on operating lines, they will receive wider acceptance resulting in improved accuracy and reliability.

An experimental and analytical study of critical spans showed that the number of critical spans increases as the wind velocity decreases, as the wind blows down the axis of the conductor and as the conductor current increases. Since all of these trends produce high conductor temperatures, the greatest need to know the location of a critical span coincides with conditions which make it most difficult to predict the location of a critical span. Therefore, while the concept of a critical span may be a very appealing one to an operating or design engineer, it is also an extremely difficult one to implement. The experimental data collected in support of the critical span study has shown that weather stations (installed to support the ampacity model) or line monitors (installed to measure the conductor temperature) must be spaced on the order of one to two miles apart when the wind velocity is low. For periods when the wind velocity is higher and more sustained, reasonable accuracy can be achieved when weather stations or line monitors are much more widely spaced. Good correlations were obtained from the program at higher wind speeds with weather stations located up to twenty five miles apart. Each utility must take into account their own geographical location, transmission routes and predominant weather patterns when siting locations for either weather stations or monitors.

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SECTION 12

APPENDICES

The following papers were presented at the Real-Time Ampacity Seminar held in Atlanta on May 20-21, 1986

Table 12. Titles of Presentations at the Real-Time Ampacity Seminars

Seminar on the Effects of Elevated Temperature Operation on Overhead Conductors and Accessories—May 20, 1986

Alurninum Conductor Elevated Temperature Considerations—
W. B. Zollars, Aluminum Conductor Products Company

High Temperature Operation of ACSR Conductors—
J. S. Barrett, Ontario Hydro

The Effect of Temperature on the Loss of Tensile Strength of Overhead Conductors—V. T. Morgan, CSIRO Division of Applied Physics

How Maximum Conductor Temperature Affects Line Costs—
D. A. Douglass, Power Technologies, Inc.

Thermal Ratings for Bare Overhead Conductors
Pennsylvania-New Jersey-Maryland (PJM) Interconnection—
Guive Nabet, Baltimore Gas & Electric Company

Current Cycling Connectors in Tension—C. B. DeLuca, P.E.,
Homac Manufacturing Company

Elevated Temperature Performance of Conductor Accessories—
W. B. Howitt, Alcoa Conductor Accessories, Inc.

Seminar on Real-Time Ampacity Ratings of Overhead Conductors—May 21, 1986

Dynamic Thermal Line Ratings Summary and Status of the
State-of-the-Art Technology—Gregory J. Ramon,
Tampa Electric Company

Considerations in the Application of Advanced Conductor
Rating Concepts—Glenn A. Davidson, CH2M Hill

The Real-Time Heat Balance for Overhead Conductors—
V. T. Morgan, CISRO Divislon of Applied Physics

DYNAMP—A Real-Time Ampacity Program for Overhead Conductors—
W. Z. Black, Georgia Institute of Technology and
R. A. Bush, Georgia Power Company

Ampacity Field Studies On Line With Low Operating Temperature—
W. A. Chisholm, Ontario Hydro

Minnesota Power Conductor Monitoring Program—
Eric R. Norberg and Andrew R. Lucero, Minnesota Power

Transmission Line Dynamic Thermal Rating Studies—
James F. Hall, Pacific Gas and Electric Company

The Table below lists those engineers who participated in the Utility Survey conducted in 1985.

Table 13. Participants in Utility Survey

Company	Name	Title
Boston Edison Company	R. W. Quinzani	Senior Electrical Engineer
Baltimore Gas and Electric Company	Guive Nabet	Senior Engineer, Electrical Engineering Department
City of Lakeland-Electrical Utilities	J. H. Curran	Supervisor, Substation Engineer
	L. Duffey	Electrical Engineer
Florida Power & Light Co.	J. G. Raine	Staff Engineer, Systems Operation
	J. Renowden	Principal Engineer Substation/ Transmission Design
	J. Rhine	Principal Engineer Substation Transmission Design
	W. R. Sooty	Senior Engineer General Engineering
Florida Power Corporation	H. E. Brown	Senior Engineer, Transmission Standards
Gainesville Regional Utilities	R. C. Watkins	Senior Engineering Assistant
Georgia Power Company	Don Smith	Transmission Planning Manager
Gulf Power Company	J. A. Babbitt	Supervisor of System Planning
Idaho Power Company	M. D. Hanson	Engineer, Transmission Dept.
	M. R. Noland	Supervisor, Power Operation
	R. W. Wall	Electronics Design Engineer
Illinois Power Company	W. L. Calhoun	Supervisor, Transmission Design
	R. L. McPherron	Supervisor, Transmission Planning
	J. D. Spencer	Director, Transmission and Distribution Design
	R. L. Trotter	Manager of Engineering
Jacksonville Electrical Authority	J. A. Dickinson	Transmission Supervisor

Table 13 (Continued)

Company	Name	Title
Madison Gas and Electric Company	L. E. Schuab	Transmission Engineer
Mississippi Power Company	T. S. Hewes	Manager, Electric Engineering and Support
Niagara Mohawk Power Corp.	J. J. Hipius	Lead Transmission Planning Engineer
Orlando Utilities Commission	R. Zell	Assistant Director, Systems Planning Division
Pacific Gas and Electric	A. C. Agboativala	Senior Energy Service Engineer, Dept. of Engineering Research
	R. S. Baishiki	Senior Electric Engineer
	R. Bunten	Senior Operations Engineer
	J. Hall	Engineer, Dept. of Engineer Research
	P. Lai	Engineer, Transmission Planning
	H. Lee	Engineer, Overhead Transmission
	J. T. Morgan	Supervising Electrical Engineer EE Department
	N. Solloway	Engineer, Transmission and Distribution
Rochester Gas & Electric Company	P. M. Callahan	Electric System Planning Engineer
Seminole Electric Co-op	W. Altman	Transmission Engineer
Southwestern Electric Power Company	W. A. Lacefield	Manager, Transmission Design
Tampa Electric Co.	R. Donahey	Assistant Manager, Systems Operations
	T. Ithier	Principal Engineer, Control Systems
	T. L. Porter	Manager, Transmission Engineering
	G. Ramon	Manager, Transmission Planning
	J. Wilsky	Senior Engineer, Control System

Table 13 (Continued)

Company	Name	Title
Tennessee Valley Authority	L. J. Berry	Supervisor Estimate Specs. and Procurement Services
Wisconsin Electric Power Co.	J. A. Becker	Transmission Planning
	P. E. Hesse	Transmission Planning
	J. P. Nesbitt	Operations Engineer, System Operations
	R. C. Nichols	Senior Project Engineer, Transmission Design
	J. W. Schriener	Systems Operator
	T. W. Wick	Project Engineer, Systems Operations
Wisconsin Public Service Corporation	R. J. Ellifson	Associate Engineer, Substation Transmission Dept.

Table 14. Utility Survey and Summary of Responses

Date: _____

Name: _____

Position/Title: _____

Company Affiliation: _____

Address: _____

Telephone: _____

SECTION I

Operation of Your Transmission and Distribution System

1. List the conductor sizes you use on your system.

Designation	Type ACSR,ACAR,etc.	MCM Area	Stranding	kV	Manufacturer

Comments:

2. Does your company have the capability to calculate its own steady state ampacity values? Yes 16 ☐ No 3 ☐

3. Does your company measure the temperature of any of its energized conductors? Yes 2 ☐ No 17 ☐

4. Does your company have the ability to monitor weather conditions such as air temperature, wind speed and wind direction throughout your service area? Yes 15 ☐ No 4 ☐

   If yes, how many weather stations do you have, what is their location and what is the size of your service area?

5. If you do not measure the weather conditions, do you routinely collect data from another source? Yes 7 ☐ No 8 ☐

   If yes, what is the source? What is the form of that data? Printed on tape etc.?

6. In your service area do you have unusual operating or weather conditions for your overhead network such as unusually high ambient temperatures, extremely high winds, isolated or sheltered lines? Yes 9 ☐ No 9 ☐

   Explain the unusual conditions.

   Area Subject to hurricanes

7. The peak power demand in your service area is: Summer 15 ☐ Winter 4 ☐

8. For the following parameters your preference for units are:

	kcmil	cm^2
Conductor area	21 ☐	1 ☐
	lbs/ft	kg/m
Mass of conductor	21 ☐	1 ☐
	in.	cm
Strand diameter	21 ☐	1 ☐
	in.	cm
O.D. of conductor	21 ☐	1 ☐
	^oF	^oC
Temperature	19 ☐	11 ☐
	ft/s	m/s
Wind Velocity	21* ☐	☐
	ohms/1000ft	ohms/m
Resistance	21 ☐	☐

* 1 vote for knots

SECTION II

Steady State Ampacity Calculations

1. How do you presently determine steady state ampacity your overhead conductors:

	Yes	No
Manufacturers tables?	11 ☐	6 ☐
In-house program or tables?	14 ☐	2 ☐
Aluminum Association Tables?	8 ☐	4 ☐
From a Standard, which one?	2 ☐	10 ☐
Other, specify?	2 ☐	6 ☐

_____

_____

_____

2. The form of your steady ampacity values is:

	Yes	No
Tabular?	16 ☐	2 ☐
Graphical?	7 ☐	5 ☐
Computer output?	11 ☐	3 ☐
Other, specify?	☐	7 ☐

_____

_____

_____

3. Are your ampacity values based on a single summer and a single winter ambient temperature? Yes 16 ☐ No 4 ☐

What are the values used for ambient air temperature?

$25^{o}C$ to $93^{o}C$ summer

$0^{o}C$ to $40^{o}C$ winter

4. Do you have separate daytime and nightime ratings? Yes 1 ☐ No 19 ☐

If yes, how do the ambient conditions differ?

5. Does your steady ampacity model consider incident solar energy on the conductor? Yes 15 ☐ No 4 ☐

If yes, what is the value for solar energy? Does it change with season?

6. Do you consider the direction of the conductor when considering the influence of sun on the conductor temperature? Yes 6 ☐ No 11 ☐

7. What values of infrared emissivity and solar absorptivity do you use in your ampacity model? ε_I = 0.5 to 0.75, α_S = 0.5 to 1.0

8. Do you consider only a single wind velocity in your steady ampacity model? Yes 15 ☐ No 0 ☐

If yes, what is the value? V = 1 to 4.4 ft/sec

If no, what is the minimum and maximum value for wind velocity and what dictates the selection between the two values? V_{max} = _____ ft/sec, V_{min} = _____ ft/sec

9. Do you assume the wind is always oriented perpendicularly to the conductor?

Yes	No
21 ☐	☐

If no, what is the angle of wind relative to the axis of the conductor? θ = _____ degrees

10. Do you calculate conductor ratings for:

	Yes	No
Normal Conditions	20 ☐	0 ☐
Emergency Operation	14 ☐	4 ☐
Fault Conditions	0 ☐	15 ☐

If yes, for emergency operation and fault conditions give estimates for time that you would expect ampacity values to be valid

Emergency time = * min

Fault time = _____ min

11. Does your steady ampacity model consider the following factors:

	Yes	No
Magnetic heating?	2 ☐	16 ☐
Temperature gradient in the conductor?	0 ☐	18 ☐
Evaporative cooling?	0 ☐	18 ☐

12. How is your ampacity information made available to your operating engineer:

	Yes	No
CRT display?	12 ☐	4 ☐
Tables?	19 ☐	0 ☐
Standards Manual?	11 ☐	4 ☐
Other, specify?	0 ☐	6 ☐

_____

_____

_____

13. What are the maximum conductor temperatures your company considers for the following conditions:

Normal?	Values ranged between 70°C and 120°C	T= ___ °C
Emergency?	Values ranged between 80°C and 140°C	T= ___ °C
Fault?	Values ranged between 90°C and 100°C	T= ___ °C

14. Are the limitations for the maximum operating temperature dictated by:

	Yes	No
Clearance?	19 ☐	0 ☐
Loss of strength?	14 ☐	4 ☐
Creep?	7 ☐	8 ☐
Degradation of terminations, splices?	8 ☐	7 ☐
Economic?	8 ☐	7 ☐
Other, specify?	0 ☐	7 ☐

ACSR - clearance is primary concern

AAC and AAAC - loss of strength is primary concern

*100 hrs at 85°C; 30 hrs at 100°C; 15 minutes short-time rating; 24 hours long-time rating; Aluminum at 110°C for 4 hours or 115°C for 15 minutes others between 10 minutes and 4 hours.

If yes, do you consider a critical span to vary from one location to another as weather and operating conditions vary or does the location remain constant?

5. If reliable line monitoring equipment were readily available in the range of $10,000-$15,000, would you consider installing it on your system?

Yes	No
12 ☐	4 ☐

If yes, approximately how many devices would you install?

3 votes for 3-4

remainder between 2 and 12

SECTION IV

Ampacity Instruction and Critical Span Analysis

1. Does your company at the present time measure the conductor temperature on any of its energized lines? Yes 3 ☐ No 16 ☐

   If yes, how many instruments are installed?

   _____

   _____

   _____

   If yes, what type of instrumentation do you use: made in-house, or manufactured by others? Briefly describe these devices?

   _____

   _____

   _____

2. Does your company have any future plans to install temperature mesuring devices on energized lines? Yes 5 ☐ No 12 ☐

3. What criteria would you use in selecting a location to install a limited number of line temperature monitors:

	Yes	No
Locations known to have thermal problems in the past	7 ☐	4 ☐
Locations on "critical spans"	12 ☐	2 ☐
Spans that are experiencing exceptional load growth	6 ☐	4 ☐
Other locations, specify	3 ☐	3 ☐

   _____

   _____

   _____

4. Does your utility utilize the concept of a "critical span" in determining the real-time rating of its network? Yes 9 ☐ No 11 ☐

   If yes, how does your company define a critical span?

   clearance below NESC minimum

   above a given temperature

   _____

   _____

6. Give important factors that should be used in providing information from a real-time ampacity model

	Yes	No
Simplicity?	18 ☐	1 ☐
Ability to handle all types of conductors and all possible weather conditions?	13 ☐	4 ☐
Completeness of information?	14 ☐	2 ☐
Others, specify?	2 ☐	5 ☐

_____

_____

_____

7. How should information from a real-time ampacity program be conveyed to the user:

	Yes	No
A conductor time constant?	5 ☐	7 ☐
A time required to reach a predetermined limiting temperature?	15 ☐	2 ☐
A set of curves that predict temperature vs. time behavior of the conductor?	5 ☐	7 ☐
Other, specify?	2 ☐	3 ☐

_____

_____

_____

8. Which ampacity method do you feel would give you the greatest confidence in knowing the temperature of the conductors in your service area:

	Yes	No
Computer model?	12 ☐	3 ☐
On-line monitors?	14 ☐	0 ☐

Explain

_____

_____

_____

If multiple answers are checked, indicate what factors dictate which limitation is considered in any application.

1. Clearance limitation is an absolute requirement
2. Loss of strength less than 10%
3. Creep when considered is calculated at 60°F
4. Harware operates at a temperature less than the conductor temperature.

SECTION III

Real-Time Ampacity Calculations

1. Does your company at the present time have the ability to predict the real-time rating of your overhead system? 5 Yes ☐ 18 No ☐

   If no, would you plan to implement a real-time rating program if it were available? 14 Yes ☐ 0 No ☐

2. Where do you feel the greatest input a real-time rating system would be within your company? Planning 9 ☐ Operations 19 ☐ Design 5 ☐

3. If a real-time conductor temperature program were available, how accurate would it have to predict the conductor temperature before you would consider using it? 13 +1°C ☐ 3 +5°C ☐ 2 +10°C ☐ 1 +20°C ☐

4. What is the priority of a real-time ampacity program within your transmission and distribution division? High 4 ☐ Moderate 9 ☐ Low 6 ☐

5. If a real-time rating program were available would your company install the program on a main frame computer or a personal computer? Yes ☐ No ☐

   If yes, state the type of computing equipment.

   4 mainframe, 6 personal computer, 9 both, 0 neither

_____

_____

_____